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An Analysis of Alternative Policies for Attaining and Maintaining a Short-Term NO2 Standard

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EXECUTIVE SUMMARY

AN ANALYSIS OF ALTERNATIVE POLICIES FOR ATTAINING AND MAINTAINING A SHORT-TERM NO_2 STANDARD

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EXECUTIVE SUMMARY

1. Introduction

This report summarizes the results of an analysis of alternative policies for implementing short-term NO_2 standards like those currently under consideration by EPA. Policy alternatives considered include an extension of current regulatory approaches to provide for control of stationary source emissions in state implementation plans, adoption of an emissions charge as a substitute for emissions limitation regulations, and adoption of a marketable permit program as a substitute for emissions limitation regulations.

Our analysis shows that the latter two alternatives (emissions charges and marketable permits) would, if appropriately designed, meet and maintain ambient standards at lower cost than would a regulatory approach. It also shows that while the practical problems of implementing a policy based upon economic incentives are not to be minimized, neither are they insurmountable. Both emissions charges and marketable emissions permits could be implemented using only currently available legal and administrative "technology". The cost savings potentially realizable to virtually all sectors of society from a policy based on economic incentives provide an enormous incentive to deal with the practical problems that would arise.

Another important finding of our analysis is that structuring policies to take account of differences between sources -- on a source-by-source basis -- will result in a substantial saving of resources required to attain ambient standards. This is true regardless of whether the control policy chosen is based on economic incentives or upon regulation. However, as will also be shown, the savings tend to be greatest under economic incentives policies. For this reason, we conclude that incentive policies are the best policy approach.

In addition to comparing economic approaches to regulatory ones, we also compare economic approaches based on emissions charges to economic approaches based on marketable permits. Our analysis shows that while both of the economic policy approaches would result in low cost attainment and maintenance of short-term NO_2 standards, the policy-administering authority would need to take much less initiative in acquiring detailed information about individual sources under a marketable permit system than under an emissions charge system. Also, marketable permit systems would be similar administratively to the permit systems now being administered by many state and local air pollution control agencies. For these reasons, we conclude that marketable emissions permits may offer the best economic policy instrument for implementing stationary source NO_x control.

It is important to qualify these conclusions by noting that we limit the scope of our investigation in several ways. The most important of these are the following:

- No systematic quantitative evaluation of the effects of uncertainty on the cost and effectiveness of alternative policies is made. However, a qualitative analysis shows that uncertainty tends to favor economic incentives approaches.
- No formal analysis is conducted of the effects of growth and technical change on optimal incentive structures. In our formal analysis, we limit ourselves to analysis of the effects of policy

alternatives on annual cost in a single year and ambient concentrations in a single year. In our quantitative calculations, we use existing emission inventory data for stationary sources, without adjustment for growth in stationary sources.

- No consideration is given to incentives that vary by time of day, or in some other seasonal fashion. However, under current technology, virtually all of control costs are fixed. Our calculations thus probably would be little different were we to consider these alternatives.

While the importance of these and other limitations in our study is not to be minimized, and while each should be addressed in further studies, we believe that the nature of our conclusions would not be materially affected by these additional investigations. On the basis of our conclusions, we recommend that serious consideration be given to implementing an economic incentive policy for air pollution control.

2. Conclusions

Our major conclusions are as follows.

ATTAINMENT AND MAINTENANCE OF A SHORT-TERM NO_2 STANDARD OF 250 $\mu g/m^3$ POSES A SERIOUS PROBLEM.

ATTAINMENT AND MAINTENANCE OF A SHORT-TERM NO_2 STANDARD OF 500 $\mu g/m^3$ DOES NOT APPEAR TO POSE A PROBLEM.

Studies show that 202 AQCR's may have one hour concentrations of NO_2 in excess of 250 $\mu g/m^3$. That is, approximately four out of five AQCR's may be in non-attainment status.

At a standard of 500 $\mu g/m^3$, very few regions would be in non-attainment status, and the cost of bringing these regions into attainment status would be low. Under these circumstances, consideration of alternatives to current regulatory approaches to pollution control for implementing a short-term NO_2 standard would be unwarranted due to the costs of policy change. Accordingly, the balance of our conclusions are predicated on the condition that a short-term standard is set that is sufficiently low to place a number of regions in non-attainment status and that the costs of attainment in these regions are significant.

> APPLICATION OF CURRENTLY AVAILABLE EMISSIONS CONTROL TECHNOLOGY WILL NOT SUFFICE TO ATTAIN AN AMBIENT STANDARD OF 250 $\mu g/m^3$ IN MANY AQCR'S. APPLICATION OF STATIONARY SOURCE CONTROLS PROJECTED TO BE AVAILABLE IN THE EARLY TO MID-1980's WILL BE REQUIRED.

Our data show that between 66 and 84 AQCR's would not attain a 250 $\mu g/m^3$ standard by 1982, and that between 26 and 50 would not have attained this level by 1990 using currently available emission controls in conjunction with the emission controls to be applied to mobile source emissions. This clearly points to the need to develop more effective emission control technology for stationary source emissions of NO_x.

> ADEQUATE TECHNOLOGY FOR CONTINUOUS MONITORING OF NO_x EMISSIONS IS CURRENTLY AVAILABLE AND THE COST OF THIS TECHNOLOGY (EXPRESSED ON AN ANNUAL BASIS) IS LESS THAN 25 PERCENT OF THE ANNUAL COST OF EMISSIONS CONTROL PROJECTED TO BE REQUIRED TO MEET SHORT-TERM STANDARDS.

We see no barriers to either regulation or pricing of emissions of stationary source NO_x emissions. Adequate technology is currently available, and the cost of this technology is not large in relation to the control outlays that will be required to meet stringent short-term standards. We believe that the cost of continuous monitoring certainly will be less than 25 percent of control costs, and more likely on the order of 5 to 10 percent of these costs.

EMISSIONS CONTROL STRATEGIES THAT TAKE ACCOUNT OF DIFFERENCES IN SOURCES' INCREMENTAL COSTS OF CONTROL AND INCREMENTAL CONTRIBUTIONS TO AMBIENT CONCENTRATIONS CAN ACHIEVE SHORT-TERM AMBIENT STANDARDS AT SIGNIFICANTLY LOWER TOTAL COST THAN CAN STRATEGIES WHICH DO NOT TAKE ACCOUNT OF THESE DIFFERENCES.

Our quantitative analysis of emissions control strategies in Chicago shows that a least cost strategy (which is designed to take account of cost and ambient contribution differences) is about one-fourth as costly as a strategy which reflects what might be achieved under today's sophisticated regulatory implementation planning methods, and only about one-tenth as costly as the strategy that reflects today's crudest regulatory implementation planning methods. In absolute terms, we conclude that a policy which would lead to adoption of something approximating a least cost strategy would save on the order of $70 million per year in the Chicago Air Quality Control Region.

EMISSIONS CHARGES AND/OR MARKETABLE PERMITS ARE EFFECTIVE POLICY INSTRUMENTS FOR IMPLEMENTING ATTAINMENT AND MAINTENANCE OF AMBIENT STANDARDS.

Our qualitative analysis shows that emissions charges and/or marketable permits will provide profit-and-loss incentives to firms to implement the degree of emissions control required to attain ambient standards. We also show that the conclusion that charges and permits are effective holds for a wide variety of assumptions about the degree of market power of sources and their organizational form. We thus have every reason to believe that charge systems and permit systems would work to implement attainment and maintenance of a short-term NO_2 ambient standard.

Most importantly, our qualitative analysis shows that emissions charges and/or marketable permits are more efficient and effective than regulatory policies (even optimal ones) in the face of uncertainty. The practical strength of incentive-based approaches to pollution control is that they tend to divide the responsibility for decision-making along roughly the same lines that detailed knowledge about the various parameters relevant to cost-effective control is divided. The result is that economic policies may be expected to result in lower costs of pollution abatement.

> EMISSIONS CHARGES AND/OR MARKETABLE PERMITS ARE AN EFFICIENT POLICY INSTRUMENT FOR IMPLEMENTING ATTAINMENT AND MAINTENANCE OF AMBIENT STANDARDS IF THEY ARE STRUCTURED TO TAKE ACCOUNT OF DIFFERENCES BETWEEN SOURCES IN INCREMENTAL CONTRIBUTIONS TO AMBIENT CONCENTRATIONS.

Our analyses show that this conclusion is supported both on theoretical and empirical grounds. Perhaps our most surprising finding is just how inefficient a charge or permit system can be if it is not structured to take account of contribution differences. In our analysis of the incentive approaches to air pollution control, we show that charge and permit systems which do not recognize these differences induce the adoption of control strategies that are markedly more costly than those which do. This result points to the conclusion that it is important, in structuring an incentive system, to come as close to setting incentives on a source-by-source basis, on the basis of contributions to ambient concentrations, as is possible. There are potentially enormous gains from doing so.

It does not follow, if practical considerations prohibit such fine distinctions between sources, that the case for an incentives based policy as an alternative to a regulatory one becomes any weaker. These same practical considerations will also constrain the extent to which regulations can be set in a manner to capitalize on differences between sources.

The telling advantage of policy based on economic incentives is that it performs better under the pervasive uncertainty which surrounds the implementation of all pollution control policies. As long as the practical considerations that constrain policy are roughly similar, or pose less severe constraints on incentives as we have argued, the superior performance of economic incentives under uncertainty tips the economic case strongly in their favor. The superior performance of incentives in inducing the development and application of emissions control technology provides still another economic argument in their favor.

> EFFICIENT EMISSIONS CHARGES AND/OR MARKETABLE PERMITS SYSTEMS IMPOSE A SMALLER ABSOLUTE BURDEN (AS MEASURED BY THE SUM OF EMISSION CONTROL COSTS PLUS CHARGE/PERMIT PAYMENTS) ON ALMOST ALL SOURCES THAN DOES ANY OTHER POLICY INSTRUMENT WE EXAMINE.

This conclusion is based on our qualitative analyses of alternative policies and our quantitative analysis of Chicago data. By "efficient" system, we mean one which takes account of sources' contributions to ambient concentrations. Our results show that only 94 of 797 sources have to control to meet ambient standards under an efficient charges or permits program, as compared with 742 of 797 sources under an assumed likely regulatory baseline. Total control costs plus charge/permit payments are about $25 million per year under efficient charges/permits systems, as against a total annual outlay of approximately $94 million under the lowest cost assumed regulatory baseline we have examined.

In reaching the conclusion that a well-structured incentive system places a smaller economic burden on society than does regulation, we also explicitly consider the possibility that regulation could be improved to incorporate cost and effectiveness tradeoffs into the regulation-making procedure. We call this brand of regulation "enlightened regulation".

In our qualitative analyses, we show that, due to imperfections in information, and due to differences in the amount and quality of knowledge possessed by the different "actors" involved in air pollution control decisions, "enlightened regulation" would tend to have higher costs than would a well-designed incentive system.

EFFICIENT CHARGES AND/OR MARKETABLE PERMITS REQUIRE THAT CHARGE LEVELS AND PERMIT PRICES VARY FROM SOURCE TO SOURCE. WHILE THE RESULTING CHARGE/PRICE LEVELS MAY VARY WIDELY, THEY MAY BE READILY EXPLAINABLE IN TERMS OF FACTORS RELATED TO CONTRIBUTIONS TO AMBIENT CONCENTRATIONS.

Our theoretical analysis establishes that efficient charge levels and permit prices generally vary from source to source. Our quantitative analysis shows that in the case of Chicago, the highest charge/price is about 700 times as large as the lowest charge/price among those sources implementing emissions controls. However, we also see that virtually 100 percent of the variation in charge levels is explained in terms of factors that probably correlate with incremental contributions to ambient pollution levels. While we believe that these "explanations", coupled with the fact that so many sources benefit by adoption of an efficient incentives program should be convincing, we also demonstrate that efficient incentives can be structured so as to eliminate or reduce the variation in charge levels/permit prices. The potential savings of efficient approaches are so large, as we have concluded above, that all parties can be given incentives to find ways to implement an efficient policy.

THERE ARE NO LEGAL BARRIERS TO THE LEGISLATION AND IMPLEMENTATION OF EITHER CHARGES OR A MARKETABLE PERMITS PROGRAM.

The analyses we examine conclude that programs can be enacted within the legitimate constitutional powers of the government and can be implemented effectively in a manner consistent with legal constraints on the exercise of government power. However, existing legislation may need to be amended explicitly to allow the implementation of such systems.

THE COSTS OF PUBLIC ADMINISTRATION OF EITHER A CHARGES OR MARKETABLE PERMITS PROGRAM WOULD BE EQUAL TO OR LESS THAN THOSE ASSOCIATED WITH THE USE OF AN EFFECTIVE REGULATORY APPROACH LIKE THAT CURRENTLY PRACTICED.

Our analysis shows that the incremental cost of administering, monitoring, and enforcing the control of stationary source emissions of NO_x will not be great in relation to the costs of emissions control under either regulation or an incentive-based approach. We do find, however, that these administrative costs are likely to be of approximately the same magnitude (or perhaps slightly lower) under either a charges or marketable permits program as they are under a regulatory program. The main reason for this is that effective regulation is projected to involve more investigation, negotiation, and litigation than would an equally effective incentive system.

A MARKETABLE PERMIT SYSTEM IS PREFERABLE TO A CHARGE SYSTEM FOR IMPLEMENTING ATTAINMENT AND MAINTENANCE OF THE SHORT-TERM NO_2 STANDARD.

We base this conclusion on the following findings of our comparative analyses of these two economic policies:

1) To implement an efficient charge system, the charge administering agency must take the initiative to acquire information about sources' control costs. This is a difficult and expensive undertaking if costs are to be determined accurately. Under a permit system, the agency does not need to take the initiative to acquire detailed source-by-source cost data. These data are revealed by sources as they buy and sell permits from one another.

2) A marketable permit system self-adjusts to inflation and growth. A charges system requires that the agency make adjustments to these factors, adjustments which depend upon uncertain and perhaps expensive data.

3) A marketable permit system can be made self-enforcing by providing for automatic surcharges on emissions in excess of those for which permits are held.

4) It is relatively easy to incorporate "equal treatment" considerations into the design of a permit system without affecting its efficiency.

5) A marketable permit system is administratively and legally similar to permit programs now operated under regulatory control programs. This means that it would be administered alongside of existing regulatory programs for other pollutants more easily than could a charge system. A marketable permit system is also close in spirit to the Offset Policy currently in force.

A MARKETABLE PERMIT SYSTEM IS A PRACTICAL ALTERNATIVE TO DIRECT REGULATION WHICH MAY ACHIEVE AMBIENT STANDARDS AT SIGNIFICANTLY LOWER TOTAL COST THAN WOULD DIRECT REGULATION. WE BELIEVE IT SHOULD BE GIVEN SERIOUS CONSIDERATION.

The potential gains from implementing pollution control through this type of policy instrument are great enough to warrant that the approach be given serious consideration. The design of a marketable permit program that we present in our study provides a fairly advanced starting point for a marketable permit option to air pollution control. There are, however, a number of details that need to be worked out. How, for example, would bids and offers to sell be communicated to the market-maker? How would data be processed and disseminated to the various market participants? Will strategic behavior be a problem, and if so, how will it be dealt with? Will monopolies of permits tend to arise? How can monopolies of permits be prosecuted under laws governing restraint of trade? What is the most suitable algorithm for matching orders? Who will do the accounting? What technical assistance would be provided to the states in starting and running a marketable permits program? These are detailed practical problems that will have to be worked out before a marketable permit system can be implemented.

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William Baumol, Sue Anne Batey Blackman, Thomas Crocker, Robert Horst, Edwin Mills, Wallace Oates, Barrett Riordan, Craig Smith, and Dianne Strassman.

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CHAPTER 1

INTRODUCTION AND SUMMARY

1.1 Introduction

This report presents the results of an analysis of alternative policies for implementing short-term NO_2 standards like those currently under consideration by EPA. Policy alternatives considered include an extension of current regulatory approaches to provide for control of stationary source emissions in state implementation plans, adoption of an emissions charge as a substitute for emissions limitation regulations, and adoption of a marketable permit program as a substitute for emissions limitation regulations.

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In addition to comparing economic approaches to regulatory ones, we also have compared economic approaches based on emissions charges to economic approaches based on marketable permits. Our analysis will show that while both of these economic policy approaches would result in low cost attainment and maintenance of short-term NO_2 standards, the policy-administering authority would need to take much less initiative in acquiring detailed information about individual sources under a marketable permit system than under an emissions charge system. Also, marketable permit systems would be similar administratively to the permit systems now being administered by many state and local air pollution control agencies. For these reasons, we have concluded that marketable emissions permits may offer the best economic policy instrument for implementing stationary source NO_2 control.

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- No formal analysis has been conducted of the effects of growth and technical change on optimal incentive structures. In our formal analysis, we have limited ourselves to analysis of the effects of policy alternatives on annual cost in a single year and ambient concentrations in a single year. In our quantitative calculations, we have used existing emission inventory data for stationary sources, without adjustment for growth in stationary sources.
- No consideration has been given to incentives that vary by time of day, or in some other seasonal fashion. However, under current technology, virtually all of control costs are fixed. Our calculations thus probably would be little different were we to consider these alternatives.

While the importance of these and other limitations in our study is not to be minimized, and while each should be addressed in further studies, we believe that the nature of our conclusions would not be affected materially by additional investigations.

1.2 Summary

The analysis which leads to these conclusions is contained in the remaining seven chapters of this report. We begin, in Chapter 2, with an overview of the NO_2 pollution problem. Our review shows that until the present time, relatively little emphasis has been placed on controlling stationary source NO_x emissions as a strategy for meeting current ambient standards for NO_2. Current strategies for meeting the existing NO_2 ambient standard (which applies to average annual concentrations) rely almost solely on the emission reductions that will be achieved by Federal mobile source emission control programs.

As is explained in Chapter 2, EPA is currently considering the adoption of a short-term standard for NO_2 concentrations to supplement the long-term standard now in force. It would be necessary to accord somewhat more emphasis to stationary source NO_x emission control if a stringent short-term ambient standard for NO_2 is adopted by EPA. Under the most stringent of short-term standards currently under consideration (250 $\mu g/m^3$ for a one hour averaging period), approximately 20 percent of the nation's air quality control regions would not be in compliance by 1985 without the imposition of controls on stationary source NO_x emissions.

Chapter 2 also shows that the stationary source emissions control technology required to reduce emissions to the levels that would be needed to meet and maintain short-term ambient standards does not exist today. Best estimates are that this technology will become available during the early- to mid-1980's. Even if the most effective currently available emissions control technologies were applied to stationary sources, several air quality control regions are projected to remain in violation of a short-term ambient standard of 250 $\mu g/m^3$.

Our examination of the status of source monitoring technology in Chapter 2 is somewhat more encouraging. In particular, we find that demonstrated commercially available technology does exist and is in use today. Moreover, the cost of this technology is relatively low.

In Chapter 3 we begin our analysis of policy alternatives for implementing stationary source NO_x emissions control strategies. Our approach in Chapter 3 is entirely qualitative. We show in this chapter why regulatory policies tend to bog down and become either ineffective, or costly, or both. The reasons, we argue in Chapter 3, are uncertainty about key information, and the procedural requirements of regulations, which frequently involve source-by-source negotiation. These procedures are very cumbersome, and the *seriatim* process to which they lead necessarily precludes any consideration of overall cost of attaining standards.

We argue in Chapter 3 that policies which rely on economic incentives perform better (i.e., have lower costs) in the face of uncertainty than do regulatory policies. We also argue that economic incentive policies are procedurally simpler and do include considerations of overall costs of attaining standards. The result, we show, is a policy that is both effective in attaining and maintaining ambient standards and low cost to society.

Two different classes of incentive policy are considered in Chapter 3. One provides incentives to reduce emissions through a specific charge on emissions set and levied by an air pollution control agency. The other produces incentives to reduce emissions by creating markets in which firms can buy and sell emissions permits. Since these permits would be costly assets, firms would have an incentive to economize on their usage by reducing emissions.

Chapter 3 also considers the possibility that an improved form of regulation, which we have called "enlightened regulation," could be implemented. The basic idea behind enlightened regulation would be to require regulatory agencies to set regulations on the basis of cost-effectiveness trade-offs. Our analysis in Chapter 3 will show that, due to uncertainty, enlightened regulation would not in general achieve ambient standards at as low a cost as would either of the kinds of economic incentives we investigate.

Each incentive policy has certain strengths and weaknesses. For example, we show in Chapter 3 that emissions charges provide a means for an orderly transition to attainment of standards pending the development of more effective and efficient emissions control technology for NO_x emissions. We also show in Chapter 3 that marketable permits programs provide a great deal of certainty concerning the level of emissions that will be realized.

The results of our investigations in Chapter 3 are, as noted above, based purely on economic theory and policy analysis, and therefore are strictly qualitative in nature. While Chapter 3 does establish that a policy that relies upon economic incentives is likely to be more effective and efficient than one which relies on a regulatory apparatus, it does not provide us with any basis for judging whether or not the advantage of an economic policy approach is likely to be sizable. To determine this requires a quantitative analysis of policy alternatives.

In Chapter 4, we describe a set of models and methods for performing a quantitative analysis of alternative policies. To be sure, each of these models and methods involves some assumptions for which there is little or no directly relevant empirical evidence. For example, our models assume that operators of emissions sources respond to incentives by seeking to minimize costs. While this assumption is a standard element of many economic models that have proven extremely satisfactory in other applications, we must essentially accept it on faith here.

In briefest terms, our quantitative analysis proceeds in two steps. First, we examine the cost and effectiveness of alternative emission control strategies. By "emission control strategy" we mean any plan specifying emissions levels to be achieved by each source. The range of alternative strategies we consider embraces those that economic policy approaches are designed to implement (which are called "least cost strategies") and those which might result from the implementation planning process as it is practiced under current regulatory policy.

The second step of our quantitative analysis examines the cost and effectiveness of specific policy design alternatives. In this analysis, we take account of both the cost and effectiveness of strategies induced by alternative policy designs and the costs of administering the policy.

Chapters 5, 6, and 7 report the results of our quantitative investigations. To provide a specific context for our analysis, we have focused on the Chicago AQCR. First, in Chapter 5, we investigate the cost and effectiveness of a number of alternative emission control strategies applied to stationary sources. Our investigation shows that strategies which take into account differences in sources' costs of control and differences in sources' contributions to ambient concentrations of NO_2 are much less costly than those which do not. In Chicago, the most efficient strategy (i.e., lowest cost) is less costly by an order of magnitude than the crudest strategy that might be adopted under a regulatory policy, and only about one-fourth as costly as a strategy which might result from a relatively sophisticated application of regulatory policy.

In Chapter 6 we analyze alternative emission charge designs for encouraging the adoption of something approximating the least cost emission control strategy. We show in this chapter that the effectiveness and efficiency properties of a charge system claimed on theoretical grounds in Chapter 3 are rather sensitive to specific design choices. We show that departures from the ideal charge design, be they purposeful or accidental, can be very costly. We also show that the likelihood of accidental error is relatively high since a great deal of difficult-to-get information is required to set charges that approximate the theoretically ideal charge. Moreover, charge rates must be adjusted to accommodate changing technologies, inflation, and growth. We conclude that because of the sensitivity of the efficiency and effectiveness properties of a charge system to these factors, and because a charge-administering agency can at best have only very imperfect information about them, only with very good fortune would an actual charge system be as efficient and effective as the theoretical ideal charge.

Chapter 7 examines the design of a marketable permit system. While this policy approach has the same desirable theoretical properties of efficiency and effectiveness possessed by an emissions charge policy, it does not require the administering agency to take the initiative in acquiring detailed source-specific cost information in order to administer a marketable permit policy. 1/ That is, in our opinion, a telling advantage. In

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1/ This does not, of course, mean that administering agencies need take absolutely no initiative to acquire cost information. Such information is required to fulfill other agency responsibilities, such as the setting of ambient standards, and preparation of economic impact statements. The point is that the agency does not need to take the initiative to estimate the type of accurate individual source cost data needed to set efficient charge levels or emissions regulations.

particular, as a practical matter, we believe that a marketable permit system can be designed which would attain and maintain ambient standards at something approximating least cost. This system would, we believe, be superior on grounds of cost and effectiveness, in comparison to a regulatory policy.

Chapter 8 restates the conclusions that we believe follow from our analysis. As noted above, our main conclusion is that adoption of a marketable permit system as a substitute for emission limitation regulations as a means to implement a short-term NO_2 ambient standard would be both relatively economical and effective.

CHAPTER 2

THE NO_X PROBLEM

2.1 Introduction

The debate over the need for controlling NO_x emissions and the regulatory mechanism through which it would be accomplished extend back to the Clean Air Act of 1970. The purpose of this chapter is to review briefly the history of the health related NO_x problem, current and anticipated regulatory requirements, the type of control systems that are available, and the ability to monitor NO_x emissions on a continuous basis.

2.2 History

2.2.1 EPA's Initial Approach to Regulating Nitrogen Oxides

One month after passage of the Clean Air Act of 1970, EPA issued AP-84 "Air Quality Criteria for Nitrogen Oxides." This document developed a case that adverse effects on human health occurred at ambient concentrations of approximately 113 micrograms per cubic meter ($\mu g/m^3$) [or 0.06 parts per million (ppm)] based on annual average. The primary evidence was from an epidemological study performed in 1968-69 by EPA on family groups and school children in Chattanooga, Tennessee, downwind of a TNT plant. The study found: (a) increased incidence of acute respiratory disease when a mean 24-hour NO_2 concentration, measured over six months, was between 117 and 205 $\mu g/m^3$; (b) increased frequency of acute bronchitis among infants exposed for two to three years; such increases were observed when the 24-hour NO_2

concentration, again measured over six months, was between 118 and 156 $\mu g/m^3$; and (c) increased risk of chronic respiratory disease in children due to reduced lung function. It is noteworthy that the exposures observed in Chattanooga, because they were continuous, were not useful as epidemological evidence for a short-term NO_2 standard, for example, exposures of one to three hours.

In April 1971, EPA established NO_2 as one of the six "criteria" pollutants to be regulated. A primary standard was established at 100 $\mu g/m^3$, annual average, to provide health protection with an adequate margin of safety. The actual health effects impact level for an annual period was thought to be 150 $\mu g/m^3$.

In late 1971, EPA published guidelines for states to use in the development of State Implementation Plans (SIP). These plans were to contain emissions standards and schedules of compliance applicable to major emissions sources of nitrogen oxides. Forty-seven air quality control regions (AQCR's) were classified in November 1971 as needing such controls. Air quality monitors in these regions had measured annual average concentrations at 110 $\mu g/m^3$ or higher. The measurement technique used to classify these regions, the Jacobs-Hochheiser (J-H) technique, was later shown to be unreliable (see below).

All states with AQCR's in violation of the NO_2 standard were to submit in early 1972, enforceable plans to reduce stationary- and mobile-source NO_x emissions to meet the standard by 1975, or 1977 if an extension were granted. Of the 29 states involved, 13 submitted acceptable plans. Sixteen did not, forcing EPA to promulgate its own plans by July 30, 1972.

While EPA was preparing these plans, the agency became aware that the J-H technique was in error. At a press conference on June 14, 1972, EPA placed implementation of its proposed plans in abeyance and urged the 13 states that had acceptable plans to do the same.

The problem with the J-H technique was twofold. First, although its calibration was based upon the assumption that 35 percent of the NO_2 present would be measured by the technique, in actuality, the collection efficiency varied with ambient concentrations. Collaborative measurements with other techniques showed that at concentrations around 100 $\mu g/m^3$ the 35 percent efficiency was a good estimate, but at lower concentrations the collection efficiency rose exponentially approaching 60 percent for a 30 $\mu g/m^3$ ambient concentration. This finding meant that EPA's measurements (that were the basis of the 1971 classification of 47 AQCR's as violating the NO_2 standard) had seriously overstated the problem. The second problem with EPA's reference technique for NO_2 measurement was less serious. It was determined that some nitric oxide (NO) was being measured as nitrogen dioxide (NO_2). This, too, made the NO_2 problem appear more serious than it was.

Along with the realization of its initial error in classifying 47 regions as NO_2 violators, EPA faced other difficult problems related to nitrogen oxides. One of these involved a separate regulatory proceeding already in progress by early 1973. The U. S. automobile companies were expected to submit in early 1975 requests that the 0.4 grams per mile (gpm) emissions standard for nitrogen oxides not be imposed on 1976 models as planned. Under the law, EPA could extend the compliance date only one year, to 1977. EPA Administrator William Ruckelshaus feared that publication of EPA's discovery that the NO_2 problem was not nearly as widespread as EPA originally believed, simultaneously with Detroit's request for a delay in compliance with the NO_x emissions standard, would appear overly fortuitous; EPA could be accused of defining away the NO_2 problem. Thus, before EPA received the extension request from the automobile companies, Ruckelshaus informed a House subcommittee on February 28, 1973, that EPA believed the NO_2 problem to be much less severe than it had thought previously, and that the need for nationwide NO_x emissions controls might not justify the 0.4 gpm standard for automobiles.

The original 90 percent reduction of automotive NO_x emissions was based on the requirements of the Los Angeles Basin. The high level of NO_2 concentrations there and reliance on measurement techniques more reliable than the J-H technique, supported a 0.4 gpm standard for that region. But EPA found it difficult to justify the standard nationwide because of the high cost per car for a second catalyst if only a handful of AQCR's had NO_2 problems. EPA's internal studies showed initially that only the existing 3.1 gpm standard could be justified. Later EPA recommended a 1.0 to 2.0 gpm range as more defensible on "technology forcing" grounds and because it could be attained without a second catalyst and without jeopardizing diesel engine production. This position was more fully developed before the Senate Subcommittee on Air and Water Pollution on April 17, 1973.

2.2.2 EPA's "New" Strategy to Regulate Nitrogen Oxides

In June 1973, EPA completed its evaluation of new air quality data from over 200 monitoring sites. EPA employed the chemiluminescence method, the continuous Saltzman method, and the arsenite method. All three showed a high degree of correlation and all three were adopted as

EPA's reference method, replacing the J-H technique. With these more reliable data, EPA announced its new strategy on June 5, 1973:

- The number of AQCR's in violation of the NO_2 standard was revised downward from 47 to two violators (Los Angeles and Chicago) and three possible violators (New York - New Jersey - Connecticut, Denver, and Salt Lake City).
- The 0.4 NO_2 automobile standard was said to be too stringent (any change would require modification of the Clean Air Act Amendments of 1970).
- The National Ambient Air Quality Standard (NAAQS) of 100 $\mu g/m^3$ for NO_2 was said to be still valid.[1/]

2.2.3 A Short-term NO_2 Standard?

Because the J-H technique was the basis for the Chattanooga study underlying the NO_2 standard, EPA was forced to reexamine the validity of the epidemological work accomplished there. The annual standard was "saved" in this instance because the concentrations measured were predominately in the 100 $\mu g/m^3$ range where the 35 percent collection efficiency assumption for the J-H method had been validated. Also important, was the availability of confirming measurements taken at the same time (1968-1969) by the U.S. Army using the Saltzman technique.

[1/] On June 8, 1973, the Federal Register reported as follows: "Based on this finding, EPA has concluded that nitrogen dioxide currently does not represent a widespread air pollution problem." (38 FR 15180)

In reexamining the Chattanooga data, EPA evaluated their validity as a basis for a short-term NO_2 standard. If short-term exposures could be correlated with respiratory or other health problems, a short-term standard could be justified. EPA was also aware of studies performed in Japan and by the World Health Organization. These data indicated short-term NO_2 exposures caused health problems similar to those EPA attributed to annual exposures. EPA concluded that if 10 percent of the one-hour-average nitrogen dioxide concentrations did not exceed 200 $\mu g/m^3$, then adverse effects on human health would be prevented. Using statistical techniques, EPA concluded that attainment of the 100 $\mu g/m^3$ annual standard would achieve this short-term criterion in every case except Chattanooga.

Since EPA reached this conclusion, several new studies have been performed and EPA has summarized its findings in a draft criteria document on the health risks associated with short-term exposures to NO_2 concentrations. However, at this time, EPA has not submitted its recommendations on a short-term nitrogen dioxide standard.

2.3 Current Provisions for Regulating NO_x

An examination of the current regulations governing the control of NO_x emissions must be addressed in two parts. First, there are those regulations that have been previously promulgated by EPA or mandated by Congress. These regulations focus primarily on mobile sources, nitric acid plants, and large stationary combustion sources such as utility power plants that were identified as the main emitters of NO_x. The second set of regulations are those that may be needed to ensure attainment and maintenance of a short-term standard. Knowledge of both aspects is important if one is to understand how economic approaches to controlling NO_x emissions might be accomplished.

Until the passage of the Clean Air Act Amendments of 1977, existing NO_x emissions regulations included performance standards for mobile sources, New Source Performance Standards (NSPS) for boilers with a firing rate in excess of 250 MMBtu/hour and nitric acid plants,[1/] and State Implementation Plans covering existing stationary sources. With the exception of the motor vehicle standards, few of these regulations represent significant compliance problems. Most of the regulations covering stationary sources require only minor modification of combustion practices with little or no cost or economic impact. The primary reasons why control on stationary sources were not more stringent were that emissions control technology was not well developed and violations of the 100 $\mu g/m^3$ NO_2 annual standard were believed to be caused mostly by mobile sources. A secondary reason was that in comparison to other criteria pollutants, violations of the annual NO_2 standard were not believed to be widespread. Table 2.3.1 shows the AQCR's in which monitoring data indicated NO_2 concentrations above or near the primary standard. With the possible exception of Los Angeles, existing controls on light duty motor vehicles were believed to be adequate to ensure attainment and maintenance.

The passage of the 1977 Amendments is likely to result in major changes in emphasis with regard to controlling NO_x emissions from stationary sources. The four most significant changes involve:

- requiring EPA to determine whether a short-term standard for NO_2 ambient concentrations is required,

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[1/] A NSPS has been proposed for stationary gas turbines.

Table 2.3.1

Urban Regions with Measured Air Quality for NO_2 in the Range of the Annual Standard (100 $\mu g/m^3$)

	Annual Average Concentration ($\mu g/m^3$)	Control Required* (%)
Los Angeles	166	40
Denver	98	no increase
New York	121	17
Philadelphia	94	no increase
Chicago	133	25
Baltimore	120	17
Canton, Ohio	113	12
Atlanta	90	no increase
Springfield, Mass.	111	10
Youngstown, Ohio	96	no increase
Steubenville, Ohio	98	no increase
Boston	128	22

* Assumes no growth in NO_x sources.

- requiring EPA to include NO_2 within the Prevention of Significant Deterioration provisions.
- requiring EPA to promulgate within five years NSPS for all major stationary sources, and fixed removal percentages for emissions from fossil-fuel-fired combustion facilities, and
- establishing 1.0 gpm NO_x as the emissions standard for light duty vehicles, and establishing a 0.4 gpm standard as solely a research goal.

The first three changes make it necessary to place increased regulatory emphasis on nitrogen oxides. The fourth change essentially shifts a greater proportion of the burden of achieving any standard from mobile to stationary sources. The most important change from the perspective of this study is the requirement that EPA determine the need for a short-term NO_2 standard.

In studies performed by EPA it is clear that high short-term concentrations of NO_2 may be caused by any one of several paths:

- mobile-source emissions,
- area-source emissions (both mobile and dispersed stationary sources),
- emissions from multiple point sources impacting the same receptor,
- emissions from isolated point sources,
- combinations of area and point sources emissions, or
- terrain impaction by a plume from a large power plant.

The relative importance of these paths is highly dependent on the level that is established as the short-term standard. EPA is currently considering a standard in the range of 250 to 1000 $\mu g/m^3$ for a one-hour averaging period. If the standard is set at the low end of this range, all of the above causes of high short-term concentrations could be important.

Preliminary results from monitoring and modeling studies being performed in support of EPA's short-term NO_2 assessment studies indicate that if a standard is set anywhere near 250 $\mu g/m^3$ it could result in a significant attainment and maintenance problem. Table 2.3.2 provides a summary of the principal results. [1/] If the standard is set at 500 $\mu g/m^3$ or above, most AQCR's should still be in compliance by 1990. The incremental cost to achieve this standard is associated primarily with some minor retrofits of stationary sources. Even if a 0.4 gpm NO_x light duty vehicle standard were implemented and significant retrofit of NO_x combustion control on stationary sources were undertaken, many AQCR's would continue to experience concentrations in excess of 250 $\mu g/m^3$. If these estimates are correct, a short-term NO_2 standard in the range of 250 $\mu g/m^3$ would result in a severe nonattainment problem, of the same magnitude as those for oxidants and total suspended particulates. Therefore, regulatory approaches directed at reducing short-term NO_2 concentrations will need to stress controls on stationary sources. The principal regulatory mechanisms that will be used to control stationary sources are described below.

[1/] The information presented is the work of the contractor, and in no way implies that EPA has accepted these results as the basis for establishing SIP guidelines.

Table 2.3.2

Attainment and Cost Evaluation (1990) For a One-Hour NO_2 NAAQS

Control Strategy	Control Costs (1979 \$ x 10^9)			
	NO_2 Standard (ppm)			
	.15		.25	
	Capital	Annual	Capital	Annual
Area Sources	<0.1	0.2	<0.1	0.1
• Mobile Source I&M Program				
• 0.4 g/mi light duty vehicle emission standard (1985)	6.7	2.0	6.7	2.0
• Space heaters and other stationary combustors	3.3	0.7	2.4	0.4
Point Sources	1.1	0.2	0.1	<0.1
Total	11.1	3.1	9.2	2.5

	NO_2 Standard (ppm)	
	.15	.25
Number of Nonattainment Areas	64	16

2.3.1 Emissions Regulations

Under Section 110 of the Clean Air Act, each state is required to submit an SIP to EPA on attainment and maintenance of the ambient air quality standards. To the extent that it is necessary to ensure attainment and maintenance of these standards, each state is required to set emissions limitations for specific sources. In most instances, these regulations are specified in terms of emissions per unit of heat input (that is, lbs NO_x/MMBtu) and calculated on the basis of linear or modified linear rollback techniques.

If a short-term standard is promulgated, existing SIP's would have to be revised to accommodate it. The degree to which individual sources might be controlled would depend upon the source's estimated contribution to high short-term concentrations and whether or not it was located in a nonattainment region. Sources located in regions expected to attain the standards would need only to control up to the point at which violations would no longer occur. For example, if an isolated point source were estimated to cause maximum ground level concentrations of 275 $\mu g/m^3$ per hour, then the degree of control required would only be 10 percent for a 250 $\mu g/m^3$ standard. However, an identical source located in an urban area with high background concentrations might be required to implement much more stringent controls. Furthermore, if it could not be demonstrated that the region would attain the standard within a reasonable period, then the source would be required to implement Reasonably Available Control Technology (RACT). Neither RACT nor its counterpart, Lowest Achievable Emission Rate (LAER) for new sources, have been defined by EPA. However, they are certain to represent fixed emissions limitations that are at least as stringent as the current SIP requirements for existing sources and NSPS requirements for new sources.

2.3.2 Offset Policy

The final element of the current regulatory strategy involves the EPA offset policy. The purpose of this policy is to ensure that if new growth is permitted in regions that are violating ambient standards, there will still be reasonable progress toward attainment.

The concept behind the offset policy is that new sources locating in nonattainment regions would have to ensure a zero or negative impact on emissions in the region by contracting with existing sources located in the region to upgrade their emissions control systems. The degree of control required would have to result in emissions reductions equal to or greater than the amount of emissions the new source would contribute.

The offset policy is, in effect, a modified market approach to air pollution control. [1] If implemented, it would create a market for emissions rights in which new sources would compete. The costs of these emissions rights would relate directly to the control costs for existing sources in upgrading their emissions control systems.

2.3.3 Summary of Existing Provisions

Existing and new regulations covering NO_x emissions will generally be based upon fixed emissions limitations. In the past, these regulations have been specified in terms of the quantity of allowable emissions per unit of heat input. The regulations for existing and new sources differ depending on whether or not the source is located in a nonattainment region.

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[1] See also Chapter 3, Section 3.4.2, p. 3-16.

If the region is expected to attain standards within a reasonable period of time, then the applicable emissions regulation would be SIP standards for existing sources and NSPS for new sources. If the region is expected to continue to experience concentrations in excess of the standard, then the applicable emissions regulation would be RACT for existing sources and LAER for new sources.[1] Sources seeking to locate in nonattainment areas must also comply with the offset policy. This means that they have to contract for additional controls on existing sources in order to reduce the net impact on regional emissions to at or below zero.

2.4 Control Technologies and Costs

2.4.1 Stationary Sources of NO_x Emissions

Figure 2.4.1.1 provides a summary of NO_x emissions from stationary sources. Stationary sources in 1974 accounted for roughly 55 percent of total NO_x emissions, of which approximately 98 percent are from combustion processes.

Combustion nitrogen oxides are formed through two separate mechanisms. Thermal NO_x results from the thermal fixation of molecular nitrogen and oxygen in the combustion air. This is the dominant mechanism associated with the firing of clean fuels. Fuel NO_x results from the oxidation of organically bound fuel nitrogen compounds. This can be the dominant mechanism associated with the firing of coal and high nitrogen content residual oils.

Table 2.4.1.1 shows the types of sources for which EPA has NO_x emissions factor estimates. These statistics are relatively complete for

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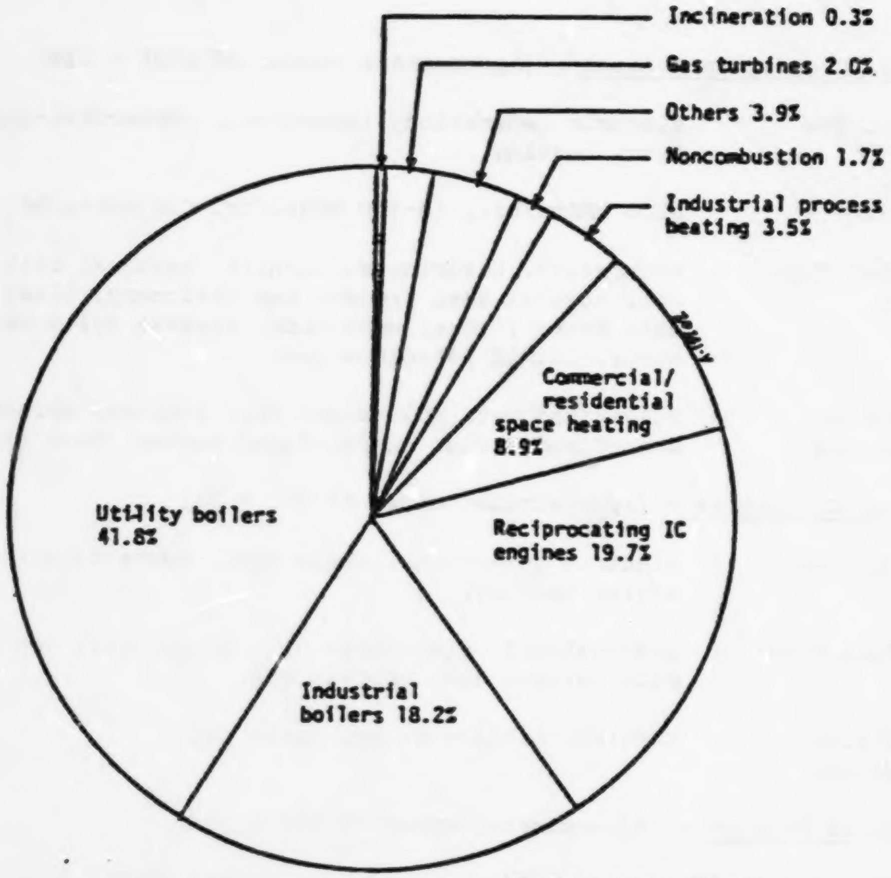
[1] Clean Air Act, Sections 172 and 173.

Figure 2.4.1.1

Summary of 1974 Stationary-Source NO_x Emissions



Source	Estimated NO_x Emissions Tg	10⁶ Tons
Utility Boilers	5.105	5.628
Industrial Boilers	2.218	2.444
Reciprocating IC Engines	2.413	2.660
Commercial/Residential Heating	1.090	1.202
Industrial Process Heating	0.432	0.476
Noncombustion	0.203	0.224
Gas Turbines	0.236	0.260
Incineration	0.034	0.043
Other	0.477	0.526
TOTAL	12.213	13.463

SOURCE: Aerotherm Corporation.

Table 2.4.1.1

Stationary NO_x Combustion and Process Sources for which EPA has Emissions Factor Estimates

External Combustion Boilers - [Approximate number of SCC* = 216]

- End Use - electric generation, industrial, commercial-institutional, space heating.
- Size - >100 MMBtu/hr., 10-100 MMBtu/hr, <10 MMBtu/hr.
- Fuel Type - anthracite, bituminous, lignite, residual oil, distillate oil, natural gas, process gas (refinery, blast furnace, coke ovens), coke, wood/bark, bagasse solid waste, liquid waste, liquid petroleum gas.
- Firing Method - Pulverized wet, pulverized dry, cyclone, spreader stoker, oven-fired stoker, under-fired stoker, hand fired.

Internal Combustion - [Approximate number of SCC = 34]

- End Use - electric generation, industrial, commercial-institutional, engine testing.
- Fuel Type - residual oil, distillate oil, diesel oil, jet fuel, crude oil, natural gas, process gas.
- Firing Method - turbine, reciprocating, turbo jet.

Industrial Process - [Approximate number of SCC = 38]

- Chemical Manufacturing - adipic acid, explosives (TNT), nitric acid, ammonia nitrate, terephthalic acid, nitrocellulose.
- Food/Agriculture - coffee roasting.
- Primary Metals - metallurgical coke, steel foundaries.
- Mineral Products - brick manufacturing, cement (dry/wet).
- Petroleum Industry - process heaters, fluid crackers, moving bed caralytic cracking.

Solid Waste - [Approximate number of SCC = 30]

- Municipal Incinerators - multiple, single chamber.
- Open Burning - general, landscape/pruning.
- Incinerators - pathological, sludge, conical.

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*SCC = Source Classification Codes

external and internal combustion sources and incinerators. The information is less complete for industrial process sources, especially for those in the direct process heat category. This may, in part, explain why industrial process emissions are one-fifth of the total amount attributed to industrial boilers even though fuel consumption by industrial process heaters is estimated to be 6.9 quads versus 6.5 quads for industrial boilers. 1/

In total, EPA has identified roughly 300 separate source categories for nitrogen oxides. Each of these has significantly different emissions characteristics. A study performed by KVB Associates for the Los Angeles Air Resources Board found that emissions characteristics even within a specific source classification code (for example, 100 MMBtu/hour gas-fired boiler) could vary by a factor of 2 to 3. 2/ The study also found that the existing emissions inventory significantly understated the contribution of stationary sources, especially in the nonboiler categories. Other important findings included a 0.8 to 1.2 variation in seasonal emissions levels and an extremely uneven distribution of emissions within the study region. 3/

2.4.2 Control Techniques

2.4.2.1 Combustion Processes

The various existing and new approaches for the control of NO_x emissions from combustion sources can be categorized as follows:

1/ Derived from EEA's Energy Consumption Data Base and Industrial Sector Technology Utilization Model.

2/ See California Air Resources Board (1974).

3/ Several industrialized areas within the basin were estimated to have emissions densities several orders of magnitude greater than average emissions over the entire basin.

- Combustion Process Modification
- Fuel Modification
- Removal of NO_x from Stack Gases [Flue Gas Treatment (FGT)]
- Alternative Combustion Processes

Combustion Process Modification. This technique consists of altering operating conditions of existing systems or altering the design of new units to minimize NO_x emissions. The underlying principle in the combustion modification is the reduction of oxygen concentration in the combustion zone and the reduction of residence time at high temperatures above 3600°F. The most effective combustion modification techniques include: low excess air firing (LEA), stoichiometric combustion through biased firing, overfire air, flue gas recirculation, low air preheat, and water injection.

Excess air is an operationally controllable parameter in most combustion processes. The reduction of oxygen in the combustor air results in excess carbon monoxide (CO) when burning gas or excess smoke when burning oil. NO_x emissions can be reduced by lowering excess air to the level just above that of the onset of excess CO or smoke. Reducing excess air from 25 to 15 percent normally results in lowering NO_x by an equivalent percentage with an additional benefit of reducing fuel requirements by one percent. Equipment for modifying the existing combustion system for LEA consists of improved oxygen measuring systems and controls. The costs of such equipment are relatively independent of size. The annual operating and maintenance costs are normally offset by the fuel savings.

Flame temperature has the most dramatic impact on the NO_x formation rate and is therefore the most important combustion modification parameter. Flame temperature can be reduced by: shifting the air-fuel ratio from the stoichiometric value in the primary flame zone; diluting the incoming air with recirculated flue gas; reducing the temperature of the incoming air; or injecting a coolant such as water or steam. [1] Each of these modifications has been found to reduce NO_x from combustion systems. Their applicability depends upon the combustion parameters of each furnace. NO_x reductions of up to 60 percent can be achieved with the application of a combination of these modifications to existing systems.

New equipment being designed incorporates one or more of the above modifications to comply with the NSPS for coal-fired boilers of 301/ng/J (0.7 lb $NO_2/10^6$ Btu). Further improvements in the burner designs are expected to continue with NO_x emissions reductions (over the present uncontrolled level) reaching 65 percent by the mid-1980's. [2]

Fuel Modification. Modification of fuel is another method used to reduce NO_x emissions. Thermal NO_x emissions are decreased by using fuels that burn at lower temperatures. The three most popular techniques are fuel switching, fuel additives, and fuel denitrification.

Solid fuels are considered to have more nitrogen than liquid fuels; gaseous fuels have virtually no nitrogen. Despite the current cost effectiveness of cleaner fuels in the control of NO_x, switching to them cannot be considered a long-range strategy because of their projected shortage in the future. With regard to using fuel additives, current evidence indicates that the emissions reductions are quite limited and that the strategy is not likely to be cost effective. At the same time, current technology for fuel denitrification generally involves fuel pretreatment to remove other pollutants. For example, marginal reductions in the nitrogen content of coal and oil have been achieved from desulfurization. However, the technique is not economically attractive if used solely for the purpose of NO_x control. Thus, if fuel denitrification is to prove cost effective, it will be on the basis of simultaneous sulfur and nitrogen removal.

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[1] Acurex (1978).

[2] *Ibid.*

Removal of NO_x from Stack Gases [Flue Gas Treatment (FGT)]. In the wake of recently increased emphasis on the control of NO_x from stationary sources, development activity for flue gas treatment of NO_x has accelerated. Several FGT processes are presently in use (or in development stages) in Japan where NO_2 standards are more stringent. Specific processes include selective catalytic reduction (SCR), selective non-catalytic reduction, and wet scrubbing. The dry systems, such as SCR using ammonia, show the most promise for clean inlet streams. The system works well with gas- or oil-fired combustion processes in which the flue gas to be scrubbed has low SO_2 and dust loading. [1] NO_x removal efficiencies of 90 percent are possible. Selective non-catalytic reduction using ammonia is being tried on a system in Japan and efficiencies of up to 70 percent have been achieved. Wet systems for the removal of NO_x from flue gas involve oxidation of NO to NO_2 with ozone or other oxidizing agents. The costs of oxidizing agents and/or energy input for generation of ozone added to the FGT costs seem to render the wet simultaneous SO_x/NO_x processes impractical for commercial use. Other combinations presently being tried for the simultaneous removal of SO_x/NO_x are wet SO_x/dry NO_x and dry SO_x/dry NO_x. The energy impact of the wet NO_x scrubbing system is discouraging. For a utility boiler the energy consumption by the wet NO_x scrubbers could be as high as 10 percent of the total plant output. But considering the trend toward increasing use of coal in the future, the wet NO_x removal processes, even though expensive, show promise because of the simultaneous SO_x/NO_x removal potential.

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[1] The use of dry SCR systems on processes using coal is not effective because of the high levels of sulfur dioxide and dust in the inlet stream, although several simultaneous SO_x/NO_x removal processes are currently under study (see below).

Alternative Combustion Processes. Fluidized bed combustion (FBC) and catalytic combustion are the major alternative combustion processes presently being explored. FBC appears to be competitive with control of conventional combustion methods from an NO_x control standpoint. However, the versatility of the FBC concept to a wide variety of equipment applications as well as the economics of its application to conventional boilers have yet to be demonstrated.

Catalytic combustion of clean fuels has been shown to limit NO_x emissions to 5 ppm, or a greater than 99 percent reduction over non-catalytic combustion units. 1/ Research work is presently continuing to demonstrate the technical feasibility of applying catalytic combustion to a variety of systems.

2.4.2.2 Non-combustion Process Control Techniques

As noted above, nitric acid manufacturing constitutes a major non-combustion source of NO_x emissions. The available control techniques include catalytic reduction, extended absorption, wet scrubbing, molecular

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1/ Acurex (1978).

sieve absorption, and flaring. Catalytic reduction is currently the most widely used NO_x control technique for nitric acid manufacturing plants. Reductions of up to 90 percent have been achieved. 1/

2.4.3 Cost and Effectiveness of Control Techniques for Stationary Sources

This section summarizes the costs and effectiveness of control techniques described earlier for the various stationary sources of NO_x. Combustion processes in which the combustion parameters are similar have been grouped together and have been assumed to require similar control techniques.

Tables 2.4.3.1 through 2.4.3.7 contain summaries of the control techniques applicable to each source category including: their effectiveness, costs, and energy impacts. The cost estimates for a control technique are for an average size source and are assumed to be linear with source size. It is important to stress the fact that most of the data in these tables are based on pilot projects with limited "field" experience. Thus, the cost effectiveness of these techniques could vary by a wide margin when applied to individual sources. The base year of the cost data is 1976 unless otherwise mentioned. The annual costs in the tables consist of the initial investment annualized at a rate of 16 percent plus annual operating and maintenance costs. 2/

1/ Acurex (1978).

2/ The 16 percent capital recovery factor assumes 100 percent debt financing, a 10 percent interest rate, and a 10-year recovery period. The actual life of most NO_x controls (i.e., those based on combustion modification techniques) would equal the remaining life of the sources controlled.

Table 2.4.3.1

Cost and Effectiveness of NO_x Controls for Existing Utility Boilers (Coal-Fired)

Control Techniques[a]	Control Potential	Earliest Year Available	Differential Control Costs		Effect On Fuel Consumption
			Initial Investment (10^2\$/10^6Btu/hr.)	Annual Cost[c] (¢/10^6Btu)[b]	
LEA	11%	Present	0.60	0.2	1.5% Decrease
LEA + OSC	22%	Present	1.25	0.5	0.5% Increase
Retrofit: Low NO_x Burner	40%	1980	2.00	0.8	0
Retrofit: Dry SCR (only NO_x)	90%	1984	60.00	26.0	3.0% Increase

[a] LEA = Low Excess Air
OSC = Off-Stoichiometric Combustion
SCR = Selective Catalytic Reduction

[b] Annual Cost = Initial investment annualized at 16 percent plus operation and maintenance costs.

[c] 1¢/10^6Btu annual heat input = 0.54 \$/kW @ 5,400 hours of operation and @ 10^4Btu = 1 kWh.
= 0.1 mil/kW hr.
Nominal heating value of coal = 28 KJ/KG (12,000 Btu/lb).

Table 2.4.3.2

Cost and Effectiveness of NO_x Controls for Existing Utility Boilers (Gas & Oil-Fired)

Control Techniques[a]	Control Potential	Earliest Year Available	Differential Control Costs		Effect On Fuel Consumption
			Initial Investment (10^2\$/10^6Btu/hr.)	Annual Cost (¢/10^6Btu)[b]	
LEA	17%	Present	0.3	Neg.	<1% Decrease
LEA + OSC	40%	Present	0.8	0.28	1% Increase
LEA + OSC + FGR	59%	Present	9.0	2.8	1% Increase
LEA + OSC + NH_3 Injection	70%	1981	8.0	14.0	>1% Increase
Retrofit: Dry SCR (NO_x only)	90%	1982	60.0	26.0	3% Increase

[a] FGR = Flue Gas Recirculation
SCR = Selective Catalytic Reduction

[b] 1¢/10^6Btu annual heat input = 0.54 \$/kW for 5,400 hours of operation @ 10^4Btu = 1 kW hr.
= 0.1 mil/kWh

Table 2.4.3.3

Cost and Effectiveness of NO_x Controls for Existing Industrial Boilers (Coal-Fired)

Control Techniques	Control Potential	Earliest Year Available	Differential Control Costs		Effect On Fuel Consumption
			Initial Investment (10^2\$/10^6Btu/hr.)	Annual Cost (¢/10^6Btu)[a]	
LEA	10%	Present	0.7	0.29	1% Decrease
LEA + OSC	20%	Present	1.8	0.66	<1% Increase
Retrofit: Low NO_x Burner	50%	1984	3.0	1.10	0
Retrofit: Dry SCR (NO_x Only)	90%	1984	50.0	23.0	3% Increase

[a] 1¢/10^6Btu annual heat input = 0.17 \$/KG/hr. steam @ 1,400 Btu/lb of steam and 5,400 hours of operation.

Table 2.4.3.4

Cost and Effectiveness of NO_x Controls for Existing Industrial Boilers (Gas & Oil-Fired)

Control Techniques	Control Potential	Earliest Year Available	Differential Control Costs		Earliest Fuel Consumption
			Initial Investment (10^2\$/10^6Btu/hr.)	Annual Cost (¢/10^6Btu)[a]	
LEA	10%	Present	0.7	0.26	1% Decrease
LEA + OSC	16%	Present	1.4	0.6	<1% Increase
Retrofit: Low NO_x Burner	50%	1981	3.0	1.1	0
Flue Gas Treatment Retrofit: Dry SCR (NO_x Only)	90%	1985	50.0	23.0	>3% Increase

[a] 1¢/10^6Btu annual heat input = 0.1 mil/kW hour.

Table 2.4.3.5

Cost and Effectiveness of NO_x Controls for Existing Industrial Process Furnaces

Control Techniques	Control Potential	Earliest Year Available	Differential Control Costs		Effect On Fuel Consumption
			Initial Investment (10^2\$/10^6Btu/hr.)[a]	Annual Cost (¢/10^6Btu)[b]	
LEA	25%	Present	1.03	0.4	1% Decrease
LEA + FGR	40%	Present	5.80	1.9	1% Increase
Advanced Design Burner New Equipment/ Retrofit	50%	1981	3.00	1.1	0
Retrofit Dry SCR (NO_x Only)	90%	1984	50.00	20.0	>2% Increase

[a] 1 kWe = 10^4Btu/hr.

[b] 1¢/10^6Btu annual heat input = 0.1 mil/kWh.

Table 2.4.3.6

Cost and Effectiveness of NO_x Controls for Existing Gas Turbines and IC Engines

Control Techniques	Control Potential	Earliest Year Available	Differential Control Costs		Effect On Fuel Consumption
			Initial Investment (10^2\$/10^6Btu/hr.)	Annual Cost (¢/10^6Btu)[a]	
Gas Turbines					
Water Injection	60%	Present	12.5	4.6	2% Increase
IC Engines					
Fine Tuning & Changing A/F	30%	Present	0	2.0	10% Increase
Retrofit Dry SCR	90%	1984	30.0	17.0	1% Increase

[a] 1¢/10^6Btu = 0.1 mil/kWh @ 10^4Btu/1 kWh.

Table 2.4.3.7

Cost and Effectiveness of NO_x Controls for Existing Nitric Acid Manufacturing Plants

Control Techniques	Control Potential	Earliest Year Available	Differential Control Costs		Effect On Fuel Consumption
			Initial Investment 10^3\$/Ton/day[a]	Annual Cost \$/Ton[a]	
Chilled Absorption	90%	Present	2.0	2.0	0

[a] 300 Tons/day - Plant capacity = 8,000 hours/year operation.

Utility Boilers. Combustion process modification (CPM) and the flue gas treatment (FGT) have been considered to be the most effective options for the control of NO_x emissions from existing utility boilers. Combustion process modification techniques have been found to be less effective on coal-fired utility boilers than on either gas- or oil-fired units. Tables 2.4.3.1 and 2.4.3.2 show the effectiveness of CPM techniques on the coal-, gas-, and oil-fired utility boilers. NO_x emissions reductions of up to 90 percent from multiple boilers may be necessary if a stringent short-term NO_2 standard is promulgated in the future. To achieve this high degree of control, FGT in conjunction with CPM may be necessary. While dry selective catalytic reduction has been demonstrated on gas- and oil-fired units with low SO_2 in the inlet stream, the flue gas must be desulfurized before dry SCR can be used for coal-fired units. Nevertheless, recent reports indicate that applications of dry SCR with special catalysts on coal-fired units are under investigation. In addition, as noted above, several simultaneous SO_x/NO_x removal processes are currently under study, although their energy consumption may make them impractical. Finally, it should be noted that several low NO_x burners are presently under development for coal-fired utility boilers. These burners would also be suitable for retrofit application. Preliminary cost projections are under $1/kW for new units and about $2/kW for retrofits and reductions in emissions from 45 to 60 percent are expected. [1]

Industrial Boilers. Combustion process modification techniques for the control of NO_x emissions from industrial boilers are effective in the range of 16 to 40 percent depending upon the fuel burned and the type of boiler. Reducing excess oxygen has been found to be more effective in reducing emissions in coal-fired boilers than in either oil- or gas-fired boilers. Retrofitting boilers with advanced design burners could boost the NO_x emissions control up to 60 percent. There are presently no data available on the costs of flue gas treatment on small industrial boilers.

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[1] See NO_x Control Review, Fall 1977.

Gas Turbines. Reductions of up to 60 percent can be realized with the application of water injection on existing gas turbines. New equipment with advanced design is expected to result in NO_x emissions reductions of up to 75 percent at an annual cost of 4 to 10 $/kW.

Internal Combustion Engines. NO_x emissions from internal combustion (IC) engines can be reduced up to 30 percent by changing air to fuel ratio. New IC engines scheduled for 1983 are expected to have NO_x emissions reduced by 50 percent.

Industrial Process Furnaces. Uncontrolled emissions from industrial process furnaces such as those associated with metallurgical, cement, and glass manufacturing vary depending on the excess air level per unit of fuel burned, though at the minimum permissible level of excess air, emissions per unit of fuel are approximately the same. NO_x reductions with LEA for different furnaces investigated is in the range of 20 to 35 percent. 1/ Furthermore, the cost of implementing low excess air modification is independent of furnace size and does not vary significantly among various processes. 2/ Adoption of advanced process tech-

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1/ Acurex (1978).

2/ Ibid.

nologies and burner designs is estimated to reduce the NO_x emissions from these furnaces by about 70 percent in the late 1980's at a cost of approximately $5/kW.

Incinerators. As shown in Figure 2.4.1.1, municipal and industrial incineration of waste is also an important source of NO_x. The only practical solution to the control of NO_x emissions from these sources is their slow phase-out and replacement with alternative solid waste disposal means. [1]

Nitric Acid Plants. Nitric acid manufacturing and other related processes using nitric acid as feedstock account for most of the non-combustion generated NO_x. Stack gas treatment employing the method listed in Table 2.4.3.7 can reduce NO_x emissions from this source category up to 90 percent.

2.5 Monitoring Capabilities

One of the most important factors to consider in developing economic approaches to controlling pollution is the adequacy of existing monitoring equipment to provide accurate and reliable data. This section presents a brief survey on the status of NO_x monitoring systems, their capabilities, and their costs.

2.5.1 Classes of Monitors

Continuous monitoring systems are either extractive or in situ. The extractive system consists of a sample acquisition device, analytical instrumentation for determining NO_x concentration and dilution factor, calibration equipment, and data recorder. [1] The principles and the equipment are much the same as those used for compliance testing of stationary sources. With in situ systems, the analyzer is mounted directly on the duct. The analyzer uses a photometric or spectroscopic concept, consisting of a light source, receiver, mounting assembly, and recorder. Calibration cells or optical filters are used to calibrate in situ devices; whereas, standard bottled gases are used to calibrate extractive systems. While nitrogen oxides and other major gaseous pollutants can be measured with either type of system, stack opacity is measured exclusively by the in situ technique.

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[1] Acurex (1978).

Table 2.5.1.1 displays the characteristics of currently available analytical instruments for extractive and in situ systems. Each type of instrument is listed with the approximate number of manufacturers, [2] the range of measuring capabilities, and a compilation of the pollutant species that the instrument can measure. [3] The instruments cost from $3,000 to $10,000 per unit. [4] Total monitoring system costs are discussed below. All of the devices meet or exceed the performance specifications (that is, an accuracy of 20 percent of the mean value of the reference method test data) established by the EPA. [5]

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[1] Sample acquisition, calibration, and data recording equipment for extractive systems are essentially the same for all extractive analytical instruments. Data recording equipment is the same for extractive and in situ systems.

[2] Apparently, only three to four manufacturers account for most of the sales of analyzers for continuous NO_x source monitors.

[3] Dual pollutant measurement capability is made possible by an added device, a thermal converter, that either oxidizes or reduces the unmeasured nitrogen oxide species into the measured species.

[4] Instrument costs reported in this section are in 1977 dollars.

[5] See Federal Register (1975).

Table 2.5.1.1

Analytical Instruments for Continuous NO_x Source Monitors

Principle of Operation	Approximate Number of Manufacturers	Measuring Range (ppm)[a]	Primary Pollutant Species Measuring Capability	Secondary Pollutant Species Measuring Capability	Accuracy (Percent of Full Scale)
Extractive					
Chemiluminescence	11	0.0001 - 20,000	NO	NO_x (NO_2 by difference)	± 1
NDIR	7	2	NO	NO_x (NO_2 by difference)	± 1
UV and Visible Photometric	5	1	NO_2	NO_x (NO by difference)	± 1
Electrochemical Transducer	3	0.1 - 50,000	NO or NO_2	--	± 1
In Situ					
Absorption Spectroscopy	1	2 - 1500	NO, SO_2, O_2	NO_x (NO_2 by difference)	± 2
Second Derivative Spectroscopy	1	? - 6000	NO, NO_2, SO_2, O_2	--	± 2

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[a] Full-scale range tailored to application; e.g., 0 - 500 ppm, 0 - 1000 ppm, or 0 - 1500 ppm.

2.5.1.1 Types of Extractive Analyzers [1/]

The analytical instruments that are currently available for use in extractive systems include chemiluminescent, nondispersive infra-red (NDIR), UV and visible photometric, and electrochemical transducer. Chemiluminescence, as shown in Table 2.5.1.1, has the lowest detection limit. This is because it is basically an ambient analyzer that has been adapted to source analysis. This sensitivity is not really necessary for a source analyzer, since NO_x concentrations are rarely below 50 ppm for any source. In the chemiluminescent technique, electronically excited NO_2 is formed from NO and O_3, and it emits light (chemiluminescence) when it reverts to its ground state. The output from a photo-multiplier measuring the light emission is linearly proportional to the NO concentration. Since the basic analyzer is sensitive only to NO, total NO_x is determined by converting (by thermal reduction) any NO_2 in the sample to NO. Estimates of NO_2 can be obtained by calculating the difference in readings with and without the converter in operation. Some major manufacturers of chemiluminescent analyzers are Aerochem Research Laboratories, Inc., Beckman Instruments, Inc., Scott Research Laboratories, Inc., and Thermo Electron Corporation. Instrument costs range from $4,000 to $8,000.

The nondispersive infra-red (NDIR) analyzer measures the difference in infra-red energy absorbed from light beams passing through a reference cell and a cell containing the gas sample. This absorption

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[1/] See Lawrence Berkeley Laboratory (1973) and Arledge *et al.* (1975) for more details.

differential is related to species concentration by using calibration curves. Like the chemiluminescent technique, NDIR is sensitive only to NO, and total NO_x is determined by converting NO_2 to NO. The NDIR technique's detectable limit is not sufficient for its use as an ambient monitor, but it is well suited for continuous source analysis. Major manufacturers of NDIR analyzers include Beckman Instruments, Inc., Bendix Corporation, and Intertech Corporation. Instrument costs range from $2,000 to $5,000.

The UV and visible photometric techniques are similar in principle to the NDIR method. The UV instrument employs a double beam arrangement through reference and sample cells and photo-multiplier tubes for detection. Manufacturers of this instrument include Peerless Instrument Co., Inc. and Beckman Instruments, Inc. Instrument costs range from $3,000 to $7,000. The visible photometric technique is based on the measurement of the difference in absorption by the sample at two separate wavelengths, one an absorbing wavelength of NO_2 in the visible region, and the other a nonabsorbing wavelength. The difference in light intensity provides a measure of the absorbing gas (NO_2 concentration). Visible photometric instrument makers include DuPont, Intertech Corp., and Teledyne. Instrument costs range from $3,000 to $10,000. The photometric technique, either UV or visible, is sensitive only to NO_2. Total NO_x is measured by converting NO to NO_2 with pressurized oxygen.

In analyzers using electrochemical transducers, NO_x (NO or NO_2, depending upon selectivity) diffuses through a semi-permeable membrane into the cell. The cell is composed of layered electrolyte and two electrodes. At the sensing electrode, the NO_x oxidizes and produces a current that flows to the counter electrode. This current is proportional to the NO_x concentration. Manufacturers of this type of instrument include Dynascience Corp., Enviro-Metrics, Inc., and Theta Sensors, Inc. Analyzer costs range from $1,000 to $8,000.

In general, the extractive method for continuously monitoring NO_x has the advantages that it can receive samples from any convenient location in the stack or duct, it provides a dry basis analysis directly (with a sample conditioning system), multipoint sampling and sample mixing are possible, and multiple analyzers can be monitored by time sharing (as is also true for *in situ* analyzers). The major disadvantages of the extraction technique are the necessity to maintain the sample acquisition equipment (for example, probes, filters), greater response time than *in situ* systems, and potential corrosion by the gas sample. In general, extractive analyzers presently on the market have evolved from laboratory and ambient models. They are historically less rugged than the *in situ* instruments, since the latter were originally designed for continuous in-stack service.

2.5.1.2 Types of "In Situ" Analyzers

In situ analyzers are based on some form of absorption spectroscopy in the near IR, UV, and/or visible portions of the spectrum. The two major types of *in situ* analyzers are the absorption spectrometer and the second-derivative spectrometer.

In the absorption spectrometer, the light source on one side of the duct emits polychromatic radiation that is collimated into multiple beams, sent through a window and across the flow of gas. A single beam from the source is used for each pollutant species to be measured. The detector receives the beams, processes them electronically, and produces an electronic signal proportional to the species concentration. Theoretically, this method has the advantage that it measures an across-the-stack average species concentration. The sole manufacturer of this type of instrument is Environmental Data Corporation at a cost of about $5,000 to $10,000 per unit.

A second-derivative spectrometer processes the transmission (I) versus wavelength (λ) function [$I = f(\lambda)$] of an ordinary spectrometer to produce an output signal proportional to the second-derivative of this function. This technique enhances the sensitivity of an ordinary spectrometer. But unlike the ordinary instrument, it measures species concentration at only one point in the stack. Lear Siegler, Inc., makes this type of instrument. Costs are about the same as that of an ordinary absorption spectrometer.

The major advantages of in situ analyzers are related to the fact that a gas sample need not be withdrawn for analysis. The problems associated with sampling (for example, probe plugging, long sample lines) are eliminated, individual unit costs are about the same as extractive systems, and the response times are faster. As with extraction analyzers, in situ instruments can be automatically calibrated. The disadvantages of in situ systems include the crucial importance of system location (to insure a representative sample), the limitations on location due to characteristics such as duct size and flow rates, the need to keep analyzer windows clean, the inability to define stratification of gases within the stream, and the fact that each sampling location requires its own monitor (as opposed to the multipoint sampling capability of one extractive analyzer).

2.5.2 Monitoring Costs

For a given source, the total installed and operating cost of a continuous monitor depends mainly upon whether the source is new or existing. For new sources, provisions for monitoring equipment can be incorporated when the plant is designed. This reduces monitor installation costs and, in some cases, operating costs. Such a pre-design advantage is not available for existing sources.

Early cost information for new sources was published by the EPA,[1] and is reproduced in Table 2.5.2.1. Limited vendor contact has determined that these costs, when inflated to 1978 prices, are probably low by ten to twenty percent. Instrument vendors, the source of these data, tend to be optimistic about installation and operating costs.

The installation costs for existing sources may vary from one to five times those for new sources, and the installation costs of opacity and gaseous monitors can be two or three times the equipment purchase price.[2] In general, this situation was verified by the vendors and users that were contacted during this study. The cost of the instrument itself, whether extractive or in situ, is small compared to all other components of the total costs (notably installation and operating costs).

1/ See Federal Register (1975).

2/ Acurex (1978).

Table 2.5.2.1

October 6, 1975 Federal Register
Costs of Continuous Monitors
(1975 Dollars)

Parameter Monitored	Installed Equipment Cost[a]	Annual Operating Cost[b]
Opacity	\$20,000	\$ 8,500
NO_x and O_2 or SO_2 and O_2	\$30,000	\$16,000
NO_x, SO_2, O_2 and opacity	\$55,000	\$30,000

[a] Includes monitor cost, installation cost, data recorder, performance testing, data reporting system and associated engineering costs.

[b] Includes data reduction and report preparation, system operation, maintenance, utilities, taxes, insurance and annualized capital costs at 10% for 8 years.

Table 2.5.2.2 summarizes the cost information obtained from the literature and from personal contacts. [1] Approximate cost ranges for each item for new and existing sources are given. Costs for either type of source are considered to be identical except for installation cost; they are higher for existing sources. Further, for an existing source, the installation costs of an in situ instrument are higher than an extractive instrument because of the need for permanent access to the monitor (for example, platforms, railings, elevators). [2]

Operating and maintenance costs depend upon whether or not the monitor has an automatic calibration device. The EPA rules for operating continuous monitors demand daily calibration. An automatic calibration device costs an additional $10,000, but will obviate the approximately one person-hour per day required for calibration. Vendor-quoted maintenance costs range from four to eight person-days/year. However, users at Southern Services and Pacific Gas and Electric have required almost one-third of a full-time person per monitor to perform a combination of maintenance and operation (including calibration) tasks. Also, one vendor (of an extractive instrument) said that the insurance costs of an in situ system would be higher than those of an extractive system because of the need to climb up to the monitor each day for calibration.

According to the vendors contacted, the design lifetimes of the continuous NO_x analyzers are about twenty years, assuming that the electronics are easily-maintainable, modular, solid-state components.

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[1] In all cases, the low ranges of the cost data came from vendors and the high ranges from users.

[2] The "heated lines" of an extractive monitor can lead down from the sample point to an existing support structure.

Table 2.5.2.2

Summary of Continuous NO_x Monitor Cost Estimates (1977)

Cost Item	Initial Cost ($\$10^3$)	Annual Cost ($\$10^3$; 15% per year)
1. NO_x, NO, NO_2 Analyzer[a]	5 - 10	0.75 - 1.5
2. Sample Conditioning System[b]	1 - 5	0.15 - 0.75
3. O_2 Analyzer[c]	2 - 5	0.3 - 0.75
4. Data System[d]	25 - 50	3.75 - 7.5
5. Installation, New Sources[e]	10 - 20	1.5 - 3
6. Installation, Existing Source[e]		
a. extractive	10 - 40	1.5 - 6
b. *in situ*	10 - 70	1.5 - 10.5
7. Operation and Maintenance[f]	--	4 - 30
Annual Cost Totals:		
• New Sources		
– extractive[g]		10.45 - 43.5
– *in situ*[h]		10 - 42
• Existing Sources		
– extractive[i]		10.45 - 46.5
– *in situ*[j]		10 - 49.5

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[a] Includes manual calibration equipment; additional $10,000 for auto-calibration

[b] Extractive analyzers only; includes probe, 20-ft. heated line, chiller, etc.

[c] Extractive analyzers only.

[d] Includes chart recorder and data acquisition device

[e] Includes: engineering, civil and electrical labor, civil and electrical materials, startup and plant personnel training.

[f] Includes: expendable materials, calibration and quarterly data reporting labor, maintenance labor and materials, utilities, insurance; use $4000 - $20,000 if auto-calibrated.

[g] Sum of 1+2+3+4+5+7

[h] Sum of 1+4+5+7

[i] Sum of 1+2+3+4+6a+7

[j] Sum of 1+4+6b+7

Actual lifetime data on the analyzers do not exist, since the oldest continuous NO_x monitor installation (Southern California Edison) has been on-line for only seven years. The lifetimes of the accessories (such as sample lines, valves) are considerably less than those of the analyzers, but are easier to replace and are less expensive. 1/

2.5.3 Applicability of Monitors to NO_x Sources

Source emissions of NO_x range from about 60 ppm for a residential gas-fired furnace to about 3,000 ppm for an uncontrolled nitric acid plant. Most of the instruments of either the extractive or in situ type can operate within this range. Extractive analyzers can be used on all sources even if the sample conditioning system is poorly designed to eliminate interferences. Physical properties of some sources (such as duct size and location) can limit the utility of in situ analyzers, but they can, with added expense, be adapted to fit most source monitoring requirements.

Cost is the major barrier to applying continuous monitors to all NO_x sources. Table 2.5.3.1 gives approximate installed costs for continuous monitors as a percentage of the capital costs of major NO_x sources. Monitoring costs are significant in relationship to total control costs for all other sources than utility boilers and stokers. This cost impact will vary considerably depending upon the capacity of the source.

According to one vendor, increased R&D and a large market demand are required before continuous NO_x monitors can be made inexpensively enough for use by the smaller NO_x sources. A large demand for monitors

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1/ Telephone interview with Mr. R. Levine (1978).

Table 2.5.3.1

Approximate Installed Costs of Major NO_x Sources and of Continuous Monitors for these Sources (1977)

NO_x Source	Unit Cost	Nominal Equipment Capacity	Cost Increase due to continuous monitor[a] (%)
Utility Boiler (Reference 13)			
coal-fired	\$320/kWe	100 MWe	0.2
oil-fired	\$240/kWe	100 MWe	0.3
gas-fired	\$100/kWe	100 MWe	0.7
Industrial Boiler (Reference 14)			
stokers	\$15-\$45/lb steam/hr	200×10^3 lb steam/hr	0.7 - 2.2
oil- and gas-fired	\$3-\$7.5/lb steam/hr	100×10^3 lb steam/hr	8.6 - 21.6
Reciprocating I.C. Engines (Reference 15)	\$300-550/hp	1500 hp	7.9 - 14.4
Gas Turbines (Reference 15)	\$250-350/hp	10^4 hp	1.9 - 2.6
Residential Furnaces (Reference 16)	\$8/10^3 Btu/hr	10^5 Btu/hr	8000

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[a] Assume average installed cost on new sources of \$65,000

will be created when the SIPs are put into effect. In addition, manufacturers seem unwilling to fund extensive in-house R&D programs unless continuous monitoring legislation for smaller sources is passed and enforced. 1/

2.5.4 Other Issues

During this study, several users and vendors of continuous NO_x monitors, as well as enforcement agencies, were contacted to gain insight into the field operating experience with monitors. Some of the earliest continuous monitor installations were in the Los Angeles Basin, and personnel from the South Coast Air Quality Management District (SCAQMD) stated that most of these monitors - absorption spectrometers - were installed on utility boilers. The users of these absorption spectrometers complain of their poor reliability and the need to stock a large, expensive inventory of scarce spare parts. Users at Southern California Edison and Pacific Gas and Electric consistently said that the devices were more costly to install and maintain and less accurate than was originally anticipated. These utilities consider this type of continuous monitor developmental and not commercial, and state further that they should not be used as enforcement tools. 2/ In contrast to these West Coast utilities, Southern Services Co. in Birmingham, Alabama, has experienced good reliability with their second-derivative spectrometer system since its installation less than a year ago. However, Southern Services' mainte-

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1/ Telephone interview with Mr. K. Luedtke (1978).

2/ Telephone interviews with Mr. R. Levine (1978) and Mr. R. Webb (1978).

nance costs (including time) have been considerably greater (by a factor of ten) than predicted by the vendor. [1]

The vendor of the absorption spectrometer installed on the West Coast utilities admitted that they have been having developmental problems, but stated that they are being solved. Furthermore, he noted that extractive analyzers are inherently more reliable than in situ devices, but on a system basis the two methods are equally reliable due to sampling problems associated with the extractive method. The two major concerns in the development of both types of continuous monitors are increased reliability and standardization of function. [2]

Both vendors and users stated that it is difficult to make the monitors tamper-proof. A "customer hands-off" maintenance contract with the vendor makes tampering less likely. In this situation, the monitor is inside an enclosure that remains padlocked between visits by the maintenance contractor. [3]

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[1] Telephone interview with Mr. R. McRanie (1978).

[2] Telephone interview with Dr. H. Lord (1978).

[3] Telephone interview with Mr. J. Wakeman (1978).

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CHAPTER 3
CONTROL POLICY ALTERNATIVES

3.1 Introduction

In this chapter we begin our examination of alternative policies for the control of NO_x emissions from stationary sources. Our objectives are to explain (1) why it is that -- absent some form of dissuasion -- emissions of air pollutants tend to be greater in amount than is consistent with acceptable ambient air quality; (2) what alternative policies can be used to dissuade emissions; and (3) the strengths and weaknesses of these alternative policies. Unlike most of the other chapters in this report which contain specific data and empirical results pertaining to the control of stationary sources to meet a short-term NO_2 standard, this chapter analyzes policy alternatives in terms of the qualitative differences which distinguish them. Though based on assumption and (admittedly) rooted in conjecture about "what would happen if? ", we shall see that fairly strong conclusions about the desirability of alternative policies can be drawn based upon a priori reasoning and casual empiricism.

The plan of the chapter is as follows. We begin in Section 3.2 with a diagnosis of the causes of unacceptable ambient air quality. The root cause is, purely and simply, that it is individually profitable to use the atmosphere as a dumping ground for wastes. Nobody owns the air, and therefore it is available to all for any use whatsoever free of charge. The result is that it is overused for disposal of wastes.

One way to deal with this problem is through direct limitation of the use of the air resource for waste disposal. This indeed is the principal policy currently being pursued to abate environmental pollution in the United States. The main instruments of this policy are regulations prescribing allowable emissions into the environment and timetables for compliance with these regulations. The specific regulations and timetables pertaining to control of NO_x emissions and proposals for new regulatory initiatives were described above in Chapter 2.

Section 3.3 analyzes briefly the strengths and weaknesses of regulatory approaches to pollution control. Its major strength, we shall see, is its definiteness about what is to be achieved and by when. Unfortunately, as we shall also see, this definiteness frequently is, in practice, more illusory than real. The procedural requirements of a direct regulatory approach seem to be such that enforcement bogs down, with the result that less-than-adequate environmental improvement is obtained.

A second potential weakness of regulatory approaches identified in Section 3.3 is that they may result in excessive expenditures of resources for the environmental improvement they produce. This is because it is extremely difficult (and quite probably even impossible) for a regulatory authority to obtain the kind of information it would need to set and enforce regulations in an efficient manner.

Section 3.4 examines alternatives to direct regulation that have been proposed to remedy these deficiencies. These alternatives grow out of the recognition that the basic cause of pollution is that it is profitable to pollute. The solution they offer is to make it unprofitable to do so through altering the prices faced by polluters.

Two general ways of doing this are considered in Section 3.4. The first way is for government to levy charges on emissions. This would cause polluters to reduce their emissions to the point where the incremental savings in charge payments obtained by reducing emissions just balanced the incremental control costs that would be incurred if emissions were further reduced.

The second way in which "emission economics" can be altered is through issuance of transferable emission permits. Each permit would entitle its holder to a stated quantity of emissions, which, when added to the entitlements of other permit holders, would result in acceptable environmental quality. The scarcity of permits reflects the limited capacity of the environment as a waste receptacle. Transfers of permits would serve to establish market prices for them, which in turn would have the same effect on the profit calculus of emitters as would charges levied on emissions (see above).

Our analysis of these two alternatives in Section 3.4 will show that approaches which directly alter emission economics possess a number of advantages in comparison with a regulatory approach. We will show that economic approaches tend to result in low-cost attainment of environmental objectives, tend to provide continuous incentives to further environmental improvement, and tend to stimulate technological change, while there is at least a presumption that regulation as it is practiced currently will not do these things.

It can be argued, and frequently is, that enlightened regulation could overcome these disadvantages. In a purely logical sense, this argument is absolutely correct. Given accurate information about all of the relevant emissions economics data, a regulatory body could prescribe regulations that would exactly duplicate the results that would be achieved by economic approaches.

The difficulty with this argument is that, in practice, a regulatory body could never obtain accurate information about all of the relevant emission economics data. How, for example, would it determine accurately individual polluters' control costs? How would it determine accurately opportunities for invention of new control methods? Perhaps the greatest strength of economic approaches relative to regulatory approaches is that they tend to locate decision-making responsibility with those who possess the information needed to make the best decision.

Section 3.5 contains a comparison of economic approaches with regulatory ones and economic approaches based upon charges with approaches based upon transferable permits. While these policy approaches are indistinguishable in the mythical world to which advocates of enlightened regulation appeal, they are quite distinguishable in the real world of costly information. Our analysis in Section 3.5 will show that the economic policy approaches (i.e., emissions charges and marketable permits) will achieve ambient standards at lower expected cost than will the most sophisticated regulatory policy that can be conceived. This conclusion is a direct consequence of the fact mentioned above that economic policy approaches tend to delegate decision-making responsibilities to those with the best information.

Section 3.5 also compares the performance of alternative policy instruments on the basis of several other criteria. We shall see, for example, that prices of transferable permits self-adjust for inflation, economic growth, and technical change. In contrast, charges and emission regulations would have to be reset to reflect these phenomena. We shall also see that market-determined permit prices may be susceptible to manipulation, whereas agency-determined emissions charges may be less susceptible.

Another extremely important conclusion of our comparative analysis in Section 3.5 is that economic policy approaches to pollution abatement would be more effective than regulatory policy approaches in inducing the development and application of new emissions control technology. While we have no firm analytical result comparing emissions charges with marketable emissions permits on the basis of their relative powers to motivate the development and application of new technology, we speculate that marketable emissions permits -- due to the certainty about the future they could provide via options and futures markets -- may provide a better stimulus to new emissions control technology.

Section 3.6 briefly summarizes the conclusions we reach in Chapter 3. Our main conclusions are these:

- First, economic policy approaches are more efficient and effective than regulatory approaches in meeting ambient standards. This conclusion is true even if a regulatory approach were pursued which purposely sought to be efficient.
- Second, economic policy approaches are more efficient and effective than regulatory approaches in motivating the development and application of new emission control technology.
- Third, a marketable emissions permit policy may be superior to a charges policy in that it (a) provides greater certainty about ambient concentrations; (b) does not require the agency to take the initiative in estimating costs in order to operate the policy;

(c) adjusts automatically to inflation, growth, and technical change; and (d) provides [through futures and options markets] a natural way to reduce intertemporal uncertainty.

3.2 The Policy Problem

The problem of air pollution is one of overutilization of a scarce resource. That resource is the waste removal capacity of the atmosphere. Although clean air has been generally viewed as a "free good", the accelerated use of the atmosphere as a low-cost means of waste (or residuals) disposal has been associated with health, property, and aesthetic damages. In order to reduce such damages, a means of rationing the waste-removal services of the atmosphere is needed.

Most goods and services in our society are rationed in the marketplace, where prices reflect society's tastes and desires and where costs reflect productive capabilities. However, there is no effective market for clean air. Thus, as suggested above, there is an overutilization of the atmosphere for disposal purposes. This, in turn, transfers to society various social costs (damages) rather than incorporating these costs as part of the production process and ultimately as part of the prices of goods and services. In such cases, economists say that an "externality" exists. That is, social costs (damages) of the pollution are not "internalized" and neither the producer nor the final consumer is directly liable for them. As a result, too many private goods and services that generate emissions are produced (at prices that are too low) and less than the optimal level of clean air (a public good) is maintained.

3.3 Regulatory Approaches

The current approach to solving the pollution control problem has concentrated primarily on regulations that change activities producing pollution or that treat pollutants once they are generated. The legislation under which the Environmental Protection Agency operates directs EPA to establish ambient environmental quality standards, and directs the EPA and state environmental agencies to establish emissions standards for individual classes of polluters. This legislation reflects a decision by Congress that the federal government must establish minimum requirements, applicable throughout the nation, for the control of environmental pollution. Furthermore, the legislation often attaches fixed deadlines to meet the requirements in the expectation that this will provide greater certainty of rapid progress in improving environmental quality.

Congress favored a uniform national policy to pollution control for several reasons. Uniform requirements for new industries that pollute inhibit states from competing for these industries on the basis of local or regional environmental standards. In addition, national uniformity simplifies marketing for manufacturers of pollution-producing products since it reduces the likelihood that such products will have to meet different standards in different areas.[1] Finally, some argue that national uniformity reduces the administrative burdens of EPA and state agencies by not requiring them to tailor standards for every polluter according to varying local or regional conditions. However, national uniformity is not costless. Several studies have shown that the use of non-uniform strategies for ambient environmental quality improvement could result in major cost savings. [1]

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[1] California's stricter automobile emissions standards present a counterexample.

There are three primary ways in which the ultimate cost of pollution control can be reduced: (1) the environmental standard, itself, can be made less ambitious; (2) the deadline at which the standard is to be met can be moved back; or (3) the methods of achieving the standards can be changed. Thus far, environmental policy has mainly followed the second course of action in dealing with pollution control. Rigid standards have been set, deadlines have been determined. When there has been a failure to meet the standards at a given point in time, in most cases deadlines have been altered. [2] In sum, the current method of regulation has been:

- placing serious burdens on EPA for developing the necessary information to promulgate regulations and to defend them in the courts;
- cumbersome to administer, requiring the negotiation of compliance schedules, issuance of permits for discharges, and renegotiations of permits when conditions change;
- difficult for EPA and state authorities to implement;
- conducive to delays of all kinds, particularly in the courts;
- imposing a degree of uniformity on polluters that is costly and sometimes unnecessary; and

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[1] See, for example, NAS (1974), Kneese and Bower (1968).

[2] The history of automobile emissions standards exemplifies this situation.

- providing no incentives for polluters to do more than the regulation requires, or to significantly reduce pollution emissions if the reduction fails to meet the standard.

Thus, we believe that there is a need for designing practical alternatives to present methods of pollution control. In some cases these alternatives might supplement existing regulations. In other instances, they might replace current regulations. Whichever way they are ultimately used, most of these alternatives embody the notion of providing economic incentives as a means to induce clean up activities by polluters. In the next section, we turn to some specific economic approaches to pollution control.

3.4 Economic Approaches

In their work on environmental policy alternatives, policy analysts have placed heavy emphasis on a central role for economic (or pricing) incentives for the regulation of polluting activities. At a formal level, this stress results from a number of important properties of a pricing solution; for example, subject to certain qualifications, the use of prices can be shown to result in the least-cost pattern of abatement across polluters. 1/ At a more pragmatic level, this policy stance derives from confidence in the profit motive. That is, by making polluting costly (or, conversely, by making pollution-abatement activities profitable), the environmental

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1/ For a formal proof of this proposition, see Baumol and Oates (1975), Chapters 4 and 10.

authority renders the polluter's self-interest consistent with society's objectives. Thus, instead of trying to enforce a set of regulatory controls that polluters have an incentive to avoid, the environmental authority can enlist the aid of market inducements to make emissions control directly profitable to individual polluters.[1]

There are several classes of economic incentives applicable to pollution control. One involves subsidies, capital allowances, or grants. A second concerns the application of pollution charges or fees. A third deals with the sale (or lease) of emissions permits. In this section we shall concentrate on the last two categories, emissions charges and emissions permits. In doing so, the basic mechanisms of each approach will be explored as well as the inherent trade-offs between the two approaches. At times it will be useful to contrast the implications of implementing these approaches with those under the current standard-setting regulatory mode.

3.4.1 Emissions Charges

The most common alternative solution to the air pollution problem proposed by policy analysts is to apply a pricing mechanism to the waste-removal services of the atmosphere. For example, one might envision a charge imposed on polluters of f dollars per ton of NO_x emitted per year. By instituting such a system, polluters have an incentive to economize on their use of the atmosphere in the same way they make decisions to employ labor and capital in an efficient manner.

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[1] Under a pricing policy, polluters will have an incentive to conceal emissions in order to reduce payments for emissions. Effective monitoring is thus necessary for the success of incentive-based approaches to pollution control, just as it is for the success of regulatory approaches.

In theory, once an emissions charge system is in place, a polluter will adjust the level of emissions abatement so that the marginal cost of controlling the last ton of emissions is balanced by the charge that would be paid if that one were emitted. Across many polluters, this means that the reduction in total emissions will be achieved at the least amount of total control costs.[1] Thus, sources whose emissions control costs are high will control less, while those with lower costs will control more. In addition, depending upon the particular characteristics of the charge scheme, the system will provide a continuing incentive for polluters to seek more efficient means of controlling emissions and reducing their charge payments.

The notion of an emissions charge and its effect on a firm's behavior can be shown diagrammatically. In Figure 3.4.1, it is assumed that a firm has a monotonically increasing marginal cost of control curve and that before the charge system is implemented, the firm is emitting E tons of NO_x per year. That is, the firm has incurred some control costs. After a charge of f dollars per ton of emissions is levied, the firm is induced to control emissions until the marginal cost of doing so is just equal to the magnitude of the charge. This equality occurs at point B in Figure 3.4.1, and corresponds to a level of emissions indicated by the distance O-A. Thus, the firm is provided with the incentive to reduce emissions by E-A. The control costs associated with the resulting level of emissions are represented by the shaded area, O'AB, and the charge payments that the firm would be making are represented by the rectangular area ABCO and are equal to f(O-A).

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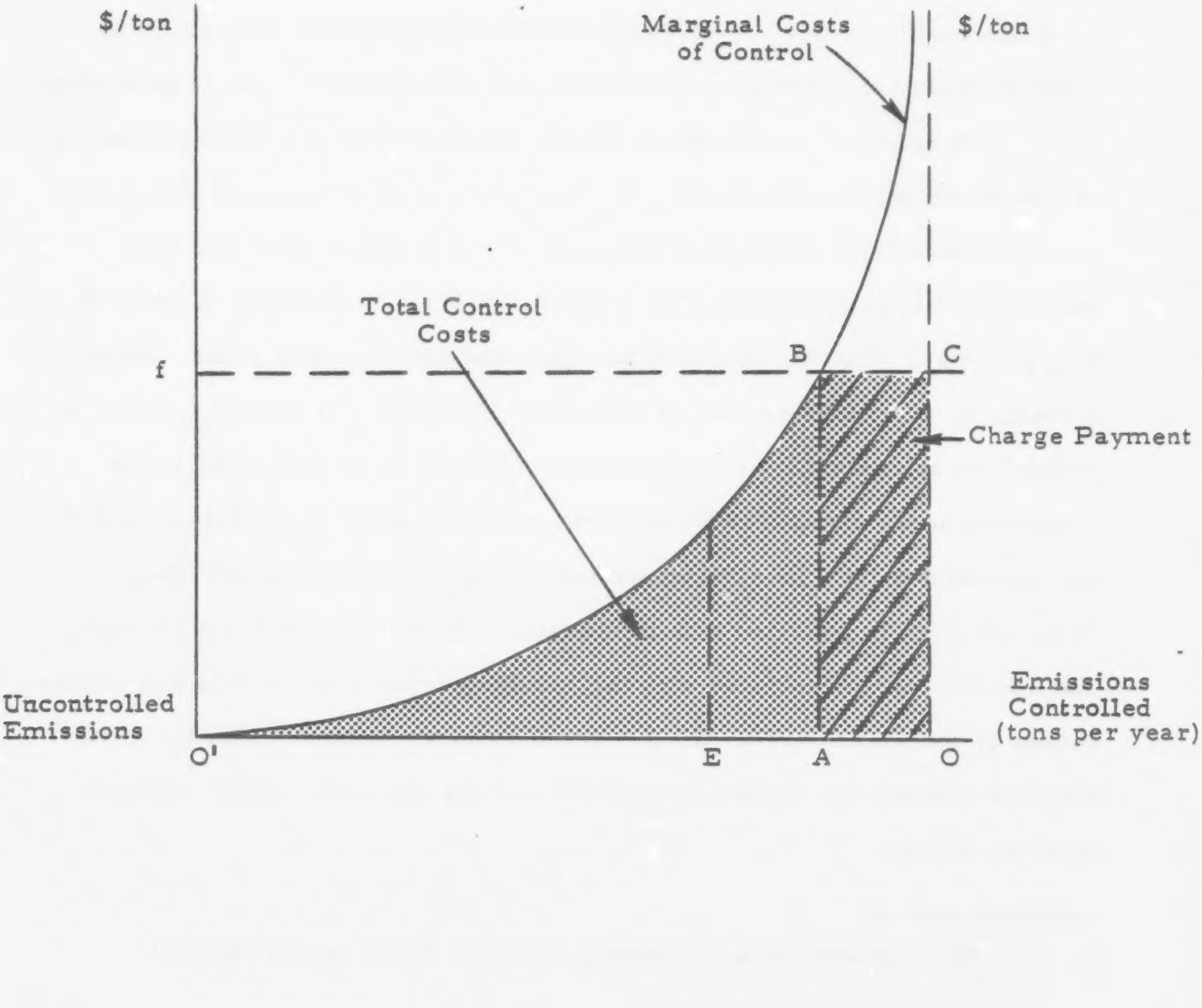
[1] For the moment, we are ignoring the costs borne by the public sector.

Figure 3.4.1

Firm Behavior in Response to an Emissions Charge



Ideally, the charge should be set on the basis of the amount of external costs associated with the pollution emissions. In other words, the charge should be set at the point where the marginal benefits (reduced damages) from pollution abatement are balanced by the marginal costs of emission control. (See Figure 3.4.2.) If a lower charge were set, the resulting level of emissions control would not be optimal because an additional dollar spent on control would reduce damages by more than a dollar. On the other hand, if a higher charge were set, the costs of additional control would exceed the benefits from that control.

In practice, the setting of charges on the basis of damages encounters some formidable obstacles. First, there is a lack of information on the damages associated with emissions. The most serious of the harmful effects of pollution often takes the form of adverse health effects (for example, increased mortality or morbidity rates). In addition, there are other costs associated with damage to materials, vegetation, and so on. Rendering these damages into quantifiable measures is a difficult task. While there have been attempts at this estimation, it is difficult to be optimistic about their widespread availability in the foreseeable future. 1/

A second obstacle concerns the fact that the optimal charge should reflect marginal social damages at the optimal level of pollution, rather than at existing levels. That is, according to Figure 3.4.2, one wants an estimate of marginal social damages in the vicinity of point A, not around

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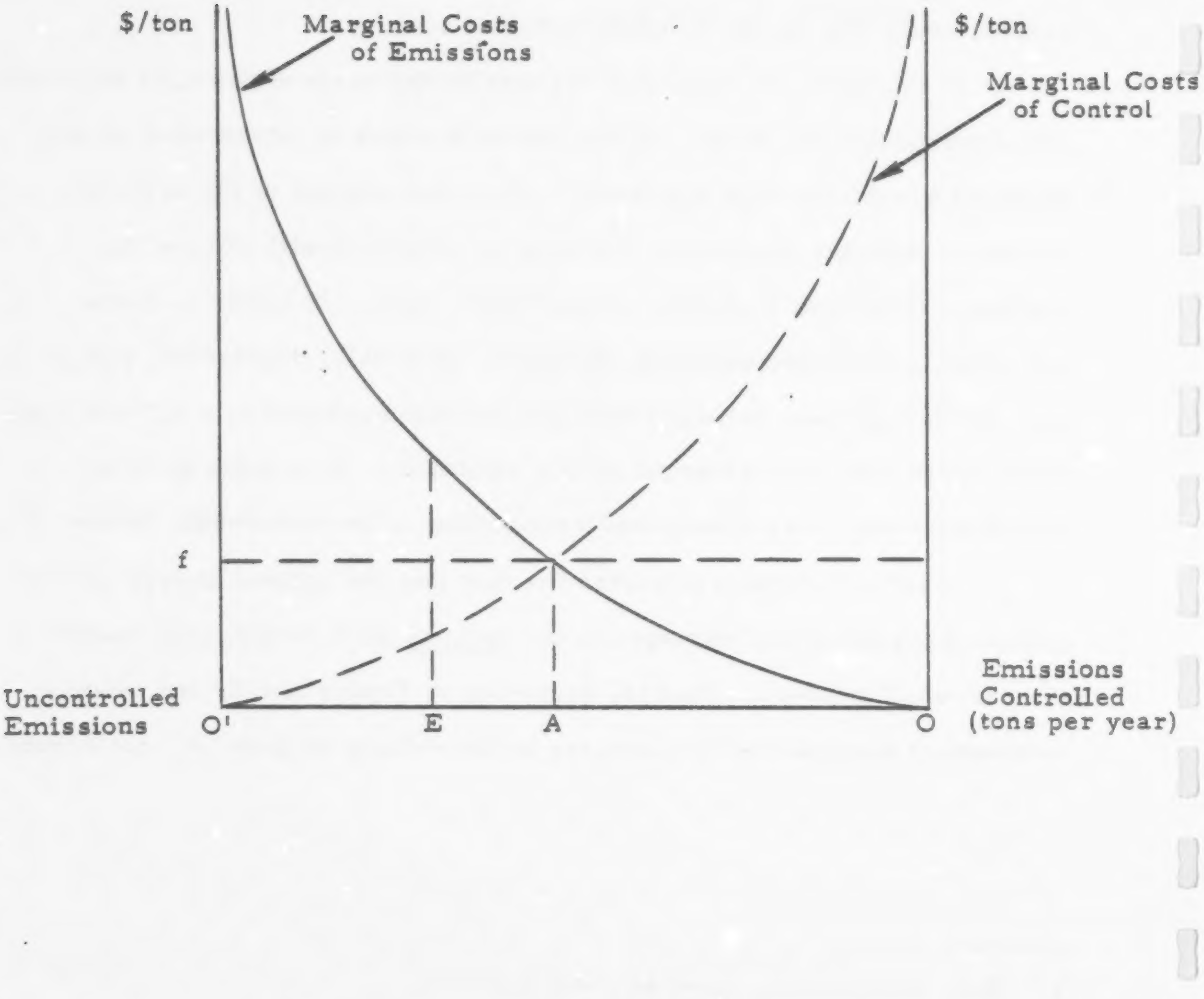
1/ See, for example, Lave and Seskin (1977).

Figure 3.4.2

Socially Optimal Level of Emissions



point E. Determining this function is, indeed, a difficult and perhaps insoluble problem. [1]

As a practical alternative to the theoretically ideal charge approach described above, another (admittedly second-best) technique for using economic incentives has been devised: the standards-and-charges approach. [2] Under this method, the environmental authority determines a set of standards for environmental quality and attempts to achieve these standards through the imposition of a system of emissions charges.

There are a number of advantages to the standards-and-charges approach. First, it circumvents the need to measure explicitly the social damages of pollution emissions. Instead, the environmental authority arrives at a set of environmental standards that hopefully take into account whatever evidence is available on damages. Second, the data on control costs needed to implement a standard and charges approach are usually much more readily available than are damage data. Third, the use of charges means that there is the potential to achieve the designated quality standards at least cost. That is, once the environmental authority sets the charge level(s) so that the corresponding reductions in emissions is consistent with the prescribed standard for environmental quality, individual responses to the charge generate automatically the least-cost pattern of abatement across polluters.

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[1] One might hope that a process of iteration in which the charge was set equal to marginal social damages at each step would lead to the optimal solution. However, aside from the costs of adjustment attendant to such a process, it is not even clear that this iterative process will converge to a global optimum. On this, see Baumol and Oates (1975), Chapter 8.

[2] See Baumol and Oates (1971) and (1975), Chapter 10.

The major disadvantage of the standards-and-charges approach is that it excludes explicit benefit considerations and focuses solely on minimizing the resource costs of pollution abatement in attaining environmental quality standards. Therefore, this type of charge system will not in general result in optimal levels of emissions reduction. This follows, since the charges that polluters pay may be more or less than the external costs that their emissions create. On the other hand, as noted above, a standards-and-charge approach potentially will bring about an administratively (or politically) chosen level of control at least cost.

3.4.2 Emissions Permits

The second commonly proposed alternative policy for dealing with air pollution is marketable emissions permits. Under a system of emissions permits, the environmental protection authority issues a fixed number of permits, each entitling the holder to emit (no more than) some specified quantity of emissions per unit of time. The key to the system is reliance on a market-related allocation method. Subsequent to the initial distribution of permits, holders of permits may buy and sell them through a regulated market. [1]

An example can be used to illustrate this type of system. Suppose there are fifty air polluters located in a given airshed. Under a permit system, the regulatory authority would determine the number of emissions permits to issue as a function of the current air quality conditions and the air quality goals. Each permit would authorize the holder to discharge, say, X pounds of NO_x per hour. The number of such permits issued by the authority would depend upon the desired ambient NO_2 levels. The attractive characteristic of the system is that the ultimate allocation of the permits depends upon a market-type transaction.

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[1] DeLucia (1974) discusses various options for the initial distribution of pollution permits. One way would be for the environmental authority to distribute permits (at no charge) among current polluters equal to a given proportion of their current emissions load, and then allow trading. Another method would use a Dutch auction. Under this plan, the environmental authority would announce a relatively high price per permit and invite "orders" at that price. If it could not sell all the permits at that price, it would void the orders and announce a lower price, and so on, until a price is reached at which all the permits could be sold. (It could speed up the process by eliciting each polluter's demand schedule and then determining the price at which the permits market would "clear.") Yet, another method would use an English auction. Under this scheme, the environmental authority would auction off multiple lots of permits, one at a time, until all permits were sold. (This is similar to the U.S. Treasury bill auctions.) However, this sort of auction may be less efficient than a Dutch auction because it can result in frustrated orders and in a gaming approach to bidding rather than bids that represent the true value of the permit to the polluter. Furthermore, under the English auction, different buyers pay different amounts; whereas, in the Dutch system, everyone pays the same price so there is a greater appearance of equity.

The efficiency properties of markets are well-known. The use of a market for emissions permits presents each polluter with an option: reduce emissions or buy permits allowing them. Thus, the polluter is continually faced with the opportunity to increase emissions by purchasing additional permits or to reduce emissions by selling permits. In this way, the price of the permit in the market creates an incentive for polluters to control emissions efficiently, just as the emissions charges do. A cost-minimizing polluter will control emissions (and buy permits) up to the point at which the marginal cost of further emissions reductions equals the price of the permit. This, in turn, has two desirable effects. First, each polluter has a continuing incentive to seek ways to reduce emissions further. Second, the market assures that the marginal costs of reducing ambient pollution will be the same across polluters since they face the same effective permit prices.[1] This implies that the ambient standards will be achieved at least cost.

We turn next to some questions regarding the functioning of a permit market. These include: On what should permits be based? Who should be allowed to participate in the market? And, what rules should apply to market transactions?

There is a very real issue in determining whether a set of permits should entitle the polluter to: (a) a given quantity of emissions, for example, 20,000 lbs. of NO_x emissions per year; (b) a given level of activity, for example, consumption of ten tons of high nitrogen content coal per year; or (c) a given incremental damage (however defined), for example, the marginal contribution to the ambient NO_2 level in the area.[2]

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[1] We are excluding the situation under an English auction as described in the preceding footnote.

[2] See also Chapter 6, Section 6.3 on Point of Application, page 6-12.

In theory, there is only one correct choice among these. One should use the last criteria, since the objective of pollution control is to reduce damage, whether physical or aesthetic, not to reduce, say, the use of high nitrogen content fuel *per se*.[1] Thus, ideally, it is better to use a measure of damage as the basis for defining emissions permits, than to use something only correlated with damage. In practice, however, compromises will be inevitable since it is usually difficult and sometimes impossible to measure (and monitor) incremental damage. Thus, one may have to "tie" the emissions permits to an activity that is easily observable and measurable, even if it is imperfectly correlated with damage. The degree of compromise that is optimal is a matter of weighing the costs and benefits of going to a more exacting measurement. The closer the chosen measure is to the actual measure of damage, the less the social loss is likely to be in terms of inducements for high-cost decisions and poor pollution control. Therefore, as a general rule of thumb, it may be best to begin by considering the ideal arrangement -- the use of a measure of damage, and then retreating from this criterion as issues of practicality necessitate.[2]

As with most markets, a market in emissions permits can be expected to function best when it is competitive and when participation is as widespread as possible.[1] This implies that, once issued, anyone should be eligible to buy or resell emissions permits at the current market price.[2] The groups who would be expected to play a role include:

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[1] As we have noted above, the same is also true for emissions charges; see Section 3.4.1 of this chapter.

[2] The phrase "emissions permits" thus anticipates a measure of damage. More generally, these permits might be called "damage permits". We will continue to use the term "emissions permits" to describe the basic permit system.

1. Polluters. This category includes industrial, individual, and governmental emitters. Because of its diversity, the system might require emissions permits in very small denominations.[3]

2. Environmentalists and other interested groups. A group that thought too many permits were issued for an area would be able to combine forces and purchase as many permits as it wished in order to withhold them from emitters.[4] Alternatively, residents within an area (either by referendum or through elected officials) would instruct the government to purchase and hold permits in order to control the levels of emissions. In this way, interested citizens

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[1] DeLucia (1974) notes that a permit system will work best where there are many polluters and when significant expenditures are anticipated for pollution control as well as when pollution amounts and sources are easily identified.

[2] DeLucia (1974) also argues that one would not limit permit holders to existing dischargers since some potential polluters might want to buy permits in advance and hold them for a period of time. Furthermore, a large and diverse number of participants in the market will reduce the likelihood that certain polluters will be in a position to manipulate the market (see below). Dales (1968) describes a permit system involving nonpolluters. Taylor (1975), in discussing a hypothetical permit system for nitrogen fertilizer use in Illinois, sees no problem with nonusers but concludes that those whose health would be affected by pollution would be unable to purchase rights in significant numbers to affect the market.

[3] Mackintosh (1973) has compared these purchases to odd-lot purchases on the stock market.

[4] Rose (1973), however, posits that if the number of permits is set at the optimal level, it will be neither necessary nor desirable for such groups to bid for rights. He assumes that the environmental authority will be able to act as an agent for nonpolluters by withholding rights from the market.

would be able to influence the composition of the economy's output and its division between consumer goods and social amenities such as environmental quality.

3. Environmental authority. The regulatory agency that issues the permits might wish to buy and sell them on its own account as a means to stabilize the market and to compensate for "thinness" of demand if it occurs. In this way, the agency would be assuming a role similar to that of a stock market specialist. [1] In addition, the presence of the agency as a buyer or seller of last resort could also eliminate lags if, for example, someone wished to sell permits but no other buyers were available. Finally, the participation of the agency could help to eliminate opportunities for large polluters to manipulate the market.

4. Speculators. If persons thought that permit prices would increase over time, they would want to purchase them and hold them for resale at a future date. While some might argue that this sort of activity is "immoral," most economists would agree that it would serve to improve the allocation of permits over time. [2] For

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[1] However, Baumol and Blackman (1978) note that experience in the securities market suggests that little is accomplished by the specialist in trying to impart "orderliness."

[2] DeLucia (1974) assumes that the speculative activity in the permit market will assure that the market works well. Mackintosh (1973) and Dales (1968) also recognize that the presence of speculators will keep the market fluid and prevent sharp fluctuations in permit prices.

example, if a miscalculation on the part of the environmental authority leads to an overabundance of permits in one period and a shortage in another, this sort of speculative activity could help to rectify the imbalance. Despite these favorable attributes, one might place some limitations on speculators. For example, one might limit the length of time for which the permits remained valid. This would prevent speculators from buying permits and holding them for resale in later periods of deliberately increased scarcity, thereby undermining the control program. [1]

With regard to other rules governing the operations of a permit market, the previously discussed analogy with the stock market may be instructive. That is, a market in emissions permits, if it is highly active, will involve specialized trading personnel such as brokers, specialists, clerks, and so one. Thus, in drafting legislation or regulations for such a market it may be appropriate to use the securities market as a model.

Emissions permits will need to designate the geographic location to which they apply. Otherwise, individual locations could not effectively adopt high standards of environmental quality or undertake strong improvement programs, since transferability of permits from other areas could undermine such objectives. The delineation of the geographic area to which a particular set of permits applies may be difficult when there is no obvious "natural" boundary. Nevertheless, the number of sources within such areas is a critical variable in setting up the system and in its ultimate feasibility. [1]

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[1] In economic theory, what is involved in the policy under discussion is intertemporal price discrimination with future prices deliberately made higher. In general, this will only work if resale from one market (time period) to another is not possible.

As suggested above, permits should also have expiration dates. The reason given earlier was to restrict speculators. Perhaps a more important one is that such limitations will allow the goals of pollution control programs to be redefined (if desired). [2] While this could also be accomplished by the repurchase of permits on the part of the issuing authority, the latter would involve transactions costs. At the same time, fixed expiration dates would automatically force the authority to rethink the size of the next batch of replacements. Moreover, unless permits had built-in expiration dates, holders would acquire a vested interest in preventing the issuance of additional permits since that would reduce the market value of their holdings.

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[1] For example, Nemetz (1977), referring to the British Columbia mining industry, concludes that because of the spatial isolation of most mines, emissions permits are not appropriate. He points out that the size of the geographical area in question as well as the comparability of pollution effects from different emitters within the area are both relevant in choosing between permit systems and other approaches to pollution control. On the other hand, Lajzerowicz and Reilly-Roe (1977), for sulfur dioxide control in British Columbia, find that permits are an attractive approach since several emitters use the same air shed and since sulfur dioxide pollution travels far and is generated by a great variety of polluters, so even isolated emitters will "compete" for available capacity. They note, however, that other pollutants are often more specific to an industry or settle more locally. Stephenson (1977) finds this to be the case for pulp and paper mills in British Columbia.

[2] Fox (1977) also points out that fixed expiration dates will prevent earlier permit holders from gaining substantial windfall profits at a later date.

In structuring a permit system, some have advocated that expiration dates for permits be staggered and that permits with different "lives" be issued. [1] In this way, unnecessary uncertainty (and its associated costs) would be reduced since polluters could seek to acquire permits whose durations were best adapted to their needs. For example, if only five-year permits were available, a construction site that needed a two-year permit would be forced to undertake the unnecessary risk that the price of permits would fall at the end of two years. On the other hand, an organization that needed permits for a very long period into the future would be subjected to unnecessary risk if, say, only annual permits were available, since it would have to forecast the prices at which it could purchase future permits. [2] By staggering permits, abrupt changes in policy (in terms of the available number of permits) would be inhibited and pollution control plans for the future could be made with greater confidence.

A related issue concerns the existence of futures markets. The primary function of futures markets is to provide insurance against risk. This, in turn, minimizes unnecessary interference with production processes. For example, it is one thing for a firm to be told in advance that pollution policy will change in some specified manner. In that case, the firm will have the opportunity to adapt plant and equipment accordingly. It is another thing to keep firms in the dark about prospective policy changes since that may simply discourage investment. A futures market helps firms to deal with such uncertainty when it is inevitable. Thus, if a plant with an expected life of twenty years is under consideration, but its profitability is marginal, a futures market may enable the firm to acquire emissions rights over the lifetime of the plant at a price it considers viable. This may make the difference between acceptance and rejection of the investment.

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[1] See deLucia (1974), Nemetz (1977), Dales (1968), and Ackerman et al. (1974).

[2] Again, there is an instructive analogy with the securities market. The prices of long-term and short-term permits would be expected to have a relation similar to the prices of long- and short-term bonds.

Similarly, the availability of options also increases the effectiveness with which firms can deal with risk. If a firm can purchase an option that entitles it to x permits t years in the future at a price of p dollars per permit, then, when the date to exercise the option arrives, the firm has two choices. If the price of permits has risen above p dollars, it can require "delivery" under the terms of the option. Alternatively, if the firm finds it no longer needs the permits, or if the market price has fallen below p dollars, the firm need not take delivery as it must under a fixed futures contract.

Thus, the availability of long-term permits, of futures markets, and of options, all serve the same basic purpose: to provide opportunities for all parties concerned to protect themselves from the effects of uncertainty. While the existence of futures markets and options give rise to speculation, as already noted, most economists agree that this is, on balance, desirable.

3.5 A Qualitative Comparison of Policy Instruments

We remarked in the introduction to this chapter that, as a counter to claims that regulation has been inefficient (in the sense that it has resulted in higher than necessary control expenditures), many observers have proposed what we have called "enlightened regulation." This latter alternative is distinguished from regulation as it is currently practiced by the fact that it would take into account differences between sources in setting emission limitations. The idea behind this proposal is to exploit the same differences between sources as are exploited by economic approaches in order to achieve reductions in the expenditures needed to attain and maintain ambient standards. That is, emissions regulations would be set on a source-by-source basis so as to attain ambient standards at least cost.

On its face, this counterproposal is appealing. It retains the basic institutional structure that has been erected to cope with environmental pollution, and it seems to promise the same benefits of effectiveness and economic efficiency that are promised by charges and marketable permits. Clearly, we must not dismiss out of hand the possibility that a regulatory approach, designed expressly to incorporate cost and effectiveness considerations, would offer the same advantages of economy and effectiveness we have attributed to economic approaches in previous sections.

The starting point for our comparison of economic approaches with enlightened regulation and between economic approaches is the observation that in a world of perfect information and costless decision-making, there need be no difference in the economic efficiency or effectiveness between approaches, whether they are based on regulation or economic incentives. The pollution control authority could set regulations that would exactly duplicate the results that would be obtained under emissions charges or under a marketable permit system. From a purely theoretical perspective, given the assumption of perfect information and costless decision-making, there are absolutely no economic reasons for preferring one type of policy to the other. The differences, if there are any differences, clearly must arise because information is imperfect and/or decision-making is not costless. [1]

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[1] Our discussion will draw heavily upon the excellent article by Martin L. Weitzman (1974).

It is well known, of course, that information in fact is not perfect, and that decision-making in fact is not costless. Experience with current regulatory policy, as has been discussed above, clearly shows just how imperfect information can be and how difficult and costly -- at least under present institutional arrangements -- it can be to achieve abatement of ambient pollution.

Among the important parameters about which there is uncertainty are control costs and their relationship to emission reductions, the relationship between emissions and ambient concentrations, the relationship between ambient concentrations and damages, technological advance in the development of control technology (including new low-pollution processes), changes in relative prices, economic growth, and so forth.

It should also be observed that the different "parties at interest" in air pollution control have different degrees of uncertainty about each of these parameters. Sources generally are less uncertain about their control costs than are authorities; sources (or the consulting engineers upon whom they rely) may be more knowledgeable about possibilities for technological advance; sources will know more about their plans for development of new locations, relocation of existing facilities, or expansions of existing facilities; control authorities will know more about the effects of emissions on ambient air quality, and the effect of ambient concentrations on the health and welfare of the community.

Uncertainty and costly decision-making are not unique to regulatory policy. Any policy must confront these realities. And our assessment of the economic performance of any policy vis-a-vis the alternatives must be based in the main on an analysis of the effects of uncertainty and decision costs on each.

The basic problem of our analysis of alternative policies is to ferret out the implications of this pervasive and assymetric uncertainty for the efficiency and effectiveness of alternative control policies. We will do so here with the aid of a simple diagrammatic analysis. [1]

What our analysis will establish is simply this: Because of uncertainty, no policy will result in exactly the right control program all of the time, or perhaps in even a single instance. We cannot be certain that costs will be minimized or that ambient standards will be met. Rather, alternative policies result in different probabilities that costs will be minimized and that standards will be met. We will see that, in general, emissions charges policies provide relatively (in relation to a regulatory policy) greater certainty that costs will be minimized, but relatively less certainty that ambient standards will be met; regulation, in contrast, will provide relatively greater certainty that standards will be met, and relatively less certainty that costs will be minimized; a marketable permit policy, we will show, provides relatively greater assurance that costs will be minimized and that standards will be met.

3.5.1 Uncertainty and the Cost and Effectiveness of Alternative Policies

To simplify our comparative analysis, we shall examine a case in which there are two sources and one receptor, and in which we will suppose that the agency is uncertain about one of the source's (which we call "source 1" below) control costs. The agency will be assumed to know exactly the other source's (i.e., "source 2") control costs and the diffusion relationships that relate units of emissions from both of the sources to concentrations at the single receptor site.

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[1] See also Section 4.3 for a more detailed mathematical analysis.

This situation is depicted in Figure 3.5.1.1 below, where we have shown source 1's marginal cost of control curves. In drawing this figure, we have assumed that source 1's marginal cost of control curve may take on one of two values, shown respectively by the curves $C(u_1)$ and $C(u_2)$, where u is a random variable.[1] We have denoted the optimum (i.e., least cost) levels of emissions from source 1 that are consistent with attainment of ambient standards by the vertical lines $\bar{e}_1$ and $\bar{e}_2$ in the figure. The former, $\bar{e}_1$, represents the optimum level of source 1's emissions if the random variable u takes on the value u_1, and $\bar{e}_2$ represents the source's optimum level of emissions if u takes on the value u_2.

The agency does not know in advance which value u will take on so it cannot set an emissions standard or an emissions charge that will be exactly correct, except by accident. Rather, the best it can hope to do is to find a policy that is best in some average sense. This indeed is a sensible objective for it to pursue. We shall assume that regardless of the particular policy instrument chosen by the agency, its goal is to minimize expected (in a mathematical sense) costs subject to the constraint that expected ambient concentrations not exceed ambient standards.

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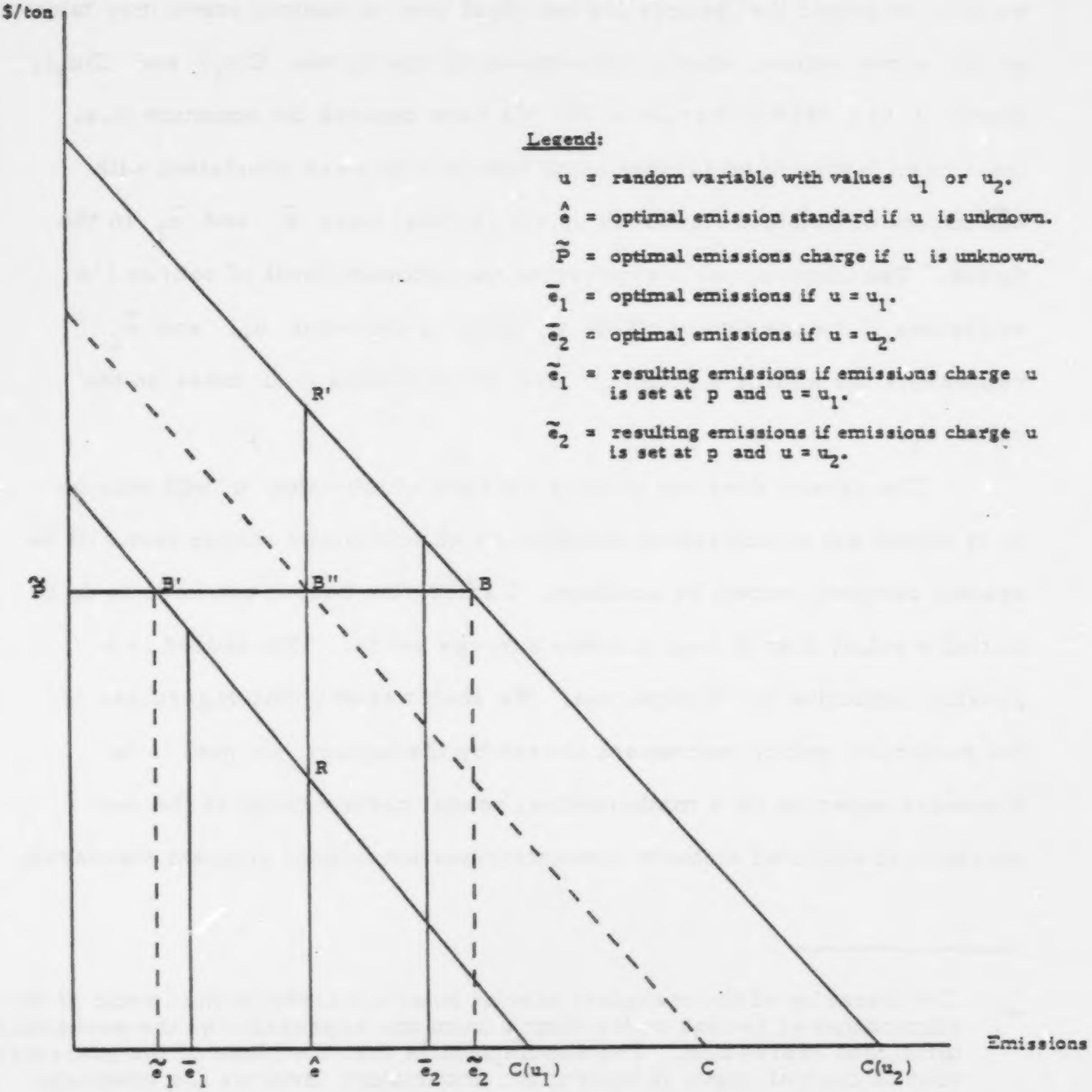
[1] The linearity of the marginal cost of control curves is the result of the elimination of second order terms from the expression of the probabilistic total cost expression. The assumption is that the slope of the marginal cost of control curve is known; the uncertainty involves the intercept. See also Section 4.3.3 on page 4-20.

Figure 3.5.1.1

Illustrative Analysis of Uncertainty



Legend:

u = random variable with values u_1 or u_2.

$\hat{e}$ = optimal emission standard if u is unknown.

$\tilde{P}$ = optimal emissions charge if u is unknown.

$\bar{e}_1$ = optimal emissions if $u = u_1$.

$\bar{e}_2$ = optimal emissions if $u = u_2$.

$\tilde{e}_1$ = resulting emissions if emissions charge u is set at p and $u = u_1$.

$\tilde{e}_2$ = resulting emissions if emissions charge u is set at p and $u = u_2$.

If this is the objective pursued by the agency, and if it chooses regulation for its policy instrument, then it can be shown that it will set an emission standard, $\hat{e}$, inside the range of values of optimum emissions levels under alternative possible cost conditions (i.e., between $\bar{e}_1$ and $\bar{e}_2$). The exact position of the emissions standard that will minimize expected costs subject to the ambient constraint depends upon the probability distribution of the uncertain marginal cost functions, the ambient standard, and the nature of the diffusion relationships.

We have drawn $\hat{e}$ in Figure 3.5.1.1 as though it fell precisely midway between $\bar{e}_1$ and $\bar{e}_2$. This would occur in fact in the situation shown if Probability $(u=u_1)$ = Probability $(u=u_2)$ = 0.5, if the diffusion parameters translating the emissions of each source into ambient concentrations at the assumed single receptor were equal, and if the marginal cost function of source 2 (shown by the dotted line "C" in Figure 3.5.1.1) fell exactly halfway between the two marginal cost functions shown for source 1.

In choosing a regulatory policy instrument, the agency has insured that it will be certain about the resulting level of emissions. Source 1 (and source 2) will emit $\hat{e}$. If diffusion relationships are known with certainty (as we have assumed here), this also implies that the agency, under regulation, would be absolutely certain that the ambient standard would be met.

This certainty about emissions and air quality comes at a cost. Inspection of Figure 3.5.1.1 shows that while the agency would be certain about the costs of control incurred by source 2, source 1's costs could either be an amount given by the triangle $\hat{e}$ R $C(u_1)$, or a somewhat larger amount given by the triangle $\hat{e}$ R' $C(u_2)$. Which cost in fact is incurred will depend upon the unknown (to the agency) value taken on by the random variable u. The cost of the certainty about emissions and ambient concentration guaranteed by a regulatory policy is thus that the costs incurred for control are uncertain, and may turn out to be very large.

As an alternative to regulation, the agency might seek to set charges on emissions that would minimize expected cost and would achieve expected ambient concentrations equal to the standard level. Such a charge is depicted in Figure 3.5.1.1 by the horizontal line, $\tilde{p}$. Under this charge, source 1's emissions are uncertain. They will either be $\tilde{e}_2$ or $\tilde{e}_1$, depending upon the value taken on by u. This means that ambient air quality also is uncertain. If u takes on the value u_2, then resulting ambient concentrations will exceed the ambient standard. If, however, it takes on the value u_1, ambient concentrations will be lower than the standard level. The charge level is set so that if we took the expected (average) value of the marginal cost functions for source 1, the resulting emissions would satisfy the ambient constraint.

While a charge policy results, as shown above, in some uncertainty about ambient concentrations, it results in perfect certainty about costs. This can be seen by examining total costs under a charge policy as shown in Figure 3.5.1.1. If u takes on the value u_2, then total costs are given by the area of the triangle $\tilde{e}_2$ B $C(u_2)$. If u takes on the value u_1, then total costs are given by the area of the triangle $\tilde{e}_1$ B' $C(u_1)$. These two triangles, it can be shown, have precisely the same area. Hence, we conclude that no matter which value u takes, total costs will be the same amount.[1/] Thus, there is no uncertainty.

[1/] Chapter 4, Section 4.3, explains the mathematical assumptions about uncertainty in cost that lead to this result.

To this point we have constructed two policies, one based on regulation and the other on emissions charges, which achieve expected ambient concentrations equal to an ambient standard. We have shown that the regulatory policy results in certainty about emissions and ambient concentrations, and uncertainty about costs. The charges policy, in contrast, results in uncertainty about emissions and ambient concentrations, and certainty about costs.

The final step of our comparison of these two policies is to examine their expected costs. To do this in our diagram, we must make use of the specific assumptions we have made for this example. [1] Expected costs under the emissions charge policy are relatively easy to compute since under our assumptions the charge policy removes uncertainty about costs. Expected costs under the charge policy are simply $\tilde{e}_2$ B C(u_2), or $\tilde{e}_1$ B' C(u_1) (which are equal). These are equal to $\hat{e}$ B'' C, which is the area we shall use to compare the expected costs of a charges policy with those of a regulatory policy.

Expected costs of a regulatory policy are given by one-half (i.e., the probability that u takes on the value u_1) times the area of the triangle $\hat{e}$ R C(u_1), (i.e., the cost when u takes on the value u_1) plus one-half (i.e., the probability that u takes on the value u_2) times $\hat{e}$ R' C(u_2) (i.e., total cost when u takes on the value u_2). Our task is to compare the sizes of this latter area with that representing the total costs of the emissions charge policy.

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[1] As noted above, most of these assumptions are relaxed in a more general mathematical analysis contained in the next chapter.

In order to compare expected total costs, we must make use of some of the specifics we have assumed in the geometric construction of the figure.[1/] Let the distance between the points R and R', and $C(u_1)$ and $C(u_2)$, be denoted by d. Further, let the distance between $\hat{e}$ and R be denoted by h and the distance between $\hat{e}$ and $C(u_1)$ be denoted by b. Then, we know, using the specifics behind the construction of Figure 3.5.1.1 that the area of the triangle representing the expected costs under an emissions charge policy is

Expected Cost Under Emissions Charge Policy =

$$\text{Area } (\hat{e}\, B''\, C) = \frac{1}{2}(b+\frac{1}{2}d)(h+\frac{1}{2}d) = \frac{1}{2}bh + \frac{1}{4}dh + \frac{1}{4}db + \frac{1}{8}d^2$$

The expected cost under a regulatory policy is given by the weighted (by the probabilities associated with alternative values of u) areas of the two triangles ($\hat{e}\, R\, C(u_1)$ and $\hat{e}\, R'\, C(u_2)$) described above. This expected value is

Expected Cost Under Regulatory Policy =

$$0.5\,(\frac{1}{2}bh) + 0.5\,(\frac{1}{2}(b+d)(h+d)) = \frac{1}{2}bh + \frac{1}{4}dh + \frac{1}{4}db + \frac{1}{4}d^2$$

A comparison of the expected cost under emissions charges with that under regulation shows that the former is smaller by the amount $\frac{1}{8}d^2$ (i.e., $\frac{1}{4}d^2 - \frac{1}{8}d^2$).

[1/] Our mathematical demonstration in the next chapter does not depend upon these specifics.

That is, we have shown (albeit under special circumstances which we will generalize in the next chapter) that the expected cost of an emissions charge policy is less than that of a regulatory policy. As noted above, however, uncertainty about resulting emissions and ambient concentrations is greater under an emissions charge policy than under a regulatory policy.

To complete our analysis, let us consider possible outcomes of a marketable emissions permit policy. Our assumption in conducting this analysis is that sources 1 and 2 know their costs of control with certainty, and reveal them in the process of buying and selling marketable permits. That is, the schedule of bids submitted by source 1, under a marketable permit policy would be either $C(u_1)$ or $C(u_2)$, depending upon the value actually taken by u, while source 2 would submit the schedule of bids C. Note that if the bidding process operates as we have assumed, at the time the agency must allocate permits to bidders, all uncertainty has been removed. In particular, it now knows what source 1's costs are with certainty. This has two consequences. First, it can be absolutely certain that the allocation of permits chosen in fact will minimize costs. Moreover, before bids are received, the agency knows that an ex post optimal decision will be made. Thus, ex ante (i.e., before bids are received) expected costs under a marketable permit policy will be precisely the same as those under an emissions charge policy.

The second consequence of knowing source 1's costs with certainty and allocating permits accordingly is that uncertainty about resulting emissions and ambient concentrations is also removed. The agency can be certain of each source's emission levels.

We conclude that a marketable permits policy and an emissions charge policy both result in lower expected control costs than does a regulatory policy. Moreover, a marketable permit policy offers as great certainty about resulting emissions and ambient air quality as does a regulatory policy, and both result in greater certainty than does an emissions charge policy.

Several qualifications, comments, and remarks on these results are in order. The first and most obvious qualification is that our results have been derived under some rather strong assumptions. While many of these will be removed in the next chapter, some will not.

The most important assumption we shall continue to make is that sources know their control costs and that in a bidding situation in which they have a legal obligation to perform as bid, reveal these costs to the control authority. This is a seemingly reasonable assumption, although there are many known instances in which bidders would not in fact reveal true reservation prices in their own interests. We have assumed, in effect, that the market is designed in a fashion to discourage or eliminate this sort of behavior.

As was hinted in the introduction, the fundamental reason our comparisons of policy alternatives turn out the way they do is because of uncertainty and assymetry of information. While in subsequent chapters we will describe the kinds of information needed to make economically sound pollution control policy and argue on *a priori* grounds that uncertainty and assymetry in fact obtain, we offer no rigorous demonstration that this is so. If there in fact is no uncertainty and assymetry, then there is no basis for concluding that one policy is likely to perform better than another.

Another limitation of our results here is that no consideration is given to differences between the costs of administering the alternative policies. It is quite possible that these costs do differ. Many policy analysts have alleged (largely on a priori grounds) that the costs of administering a policy based upon emissions charges or marketable permits would be substantially greater than would the costs of administering regulation. While this may or may not be so, it should be pointed out that most of these analysts implicitly assume a continuation of regulation as currently practiced, and not the kind of "enlightened regulation" we have analyzed above. Under enlightened regulation, it is probable that administrative costs would be at least as great as under emissions charges or marketable permits. If enlightened regulation were to require the same procedures as are followed under current regulation, it is conceivable that enlightened regulation would be vastly more expensive than either of the alternatives, and perhaps altogether infeasible.

Having discussed the basic characteristics of regulatory systems, emissions charge systems and emissions permit systems, we turn now to a comparison of policy instruments in terms of several criteria other than cost and effectiveness.

3.5.2 Inducement of Technological Change

An important objective of current national pollution control policy is the development of new, more effective and lower cost pollution control technology. Many provisions of law are intended to be "technology forcing". Yet perhaps the greatest weakness of current regulatory approaches is the strong possibility that they stifle rather than encourage the development of new pollution control technology. This is because under regulation, sources know that development of more effective technology probably will lead to the setting of more stringent and costly emissions limitations. Provisions of the law that require the application of "reasonably available control technology" or "lowest achievable emission rate" or "best available technology" virtually guarantee that more stringent limitations will be the outcome of efforts to develop new methods. In consequence, sources have a strong incentive to do absolutely nothing to develop new technology, or, if they do, to make sure that developments are concealed from regulators.

The situation under economic incentive policies is quite different. Confronted with the requirement to pay a charge or to purchase permits to cover emissions, sources have a continuing incentive to search for technologies that will result in lower costs (i.e., charge or permit payments plus control costs) than those associated with currently available technologies. This, in turn, tends to lead to the development and application of more effective control technology.

The reasoning which leads to these conclusions can be illustrated by means of a diagram similar to that we have used above in Figure 3.4.1 to explain the basic operation of a charge system. In Figure 3.5.1 below, we have drawn a hypothetical long run marginal cost of control curve for a source as the step function O'-LMC. Each "step" corresponds to a different emission control technology. The permit price or charge per unit of emissions is given by the line f-f. At this incentive level, according to the reasoning reviewed in Section 3.4 (see Figure 3.4.1), the source would reduce emissions by the amount O'-A and would emit O-A and pay f(O-A). [1] Total control costs plus payments (of charges or for

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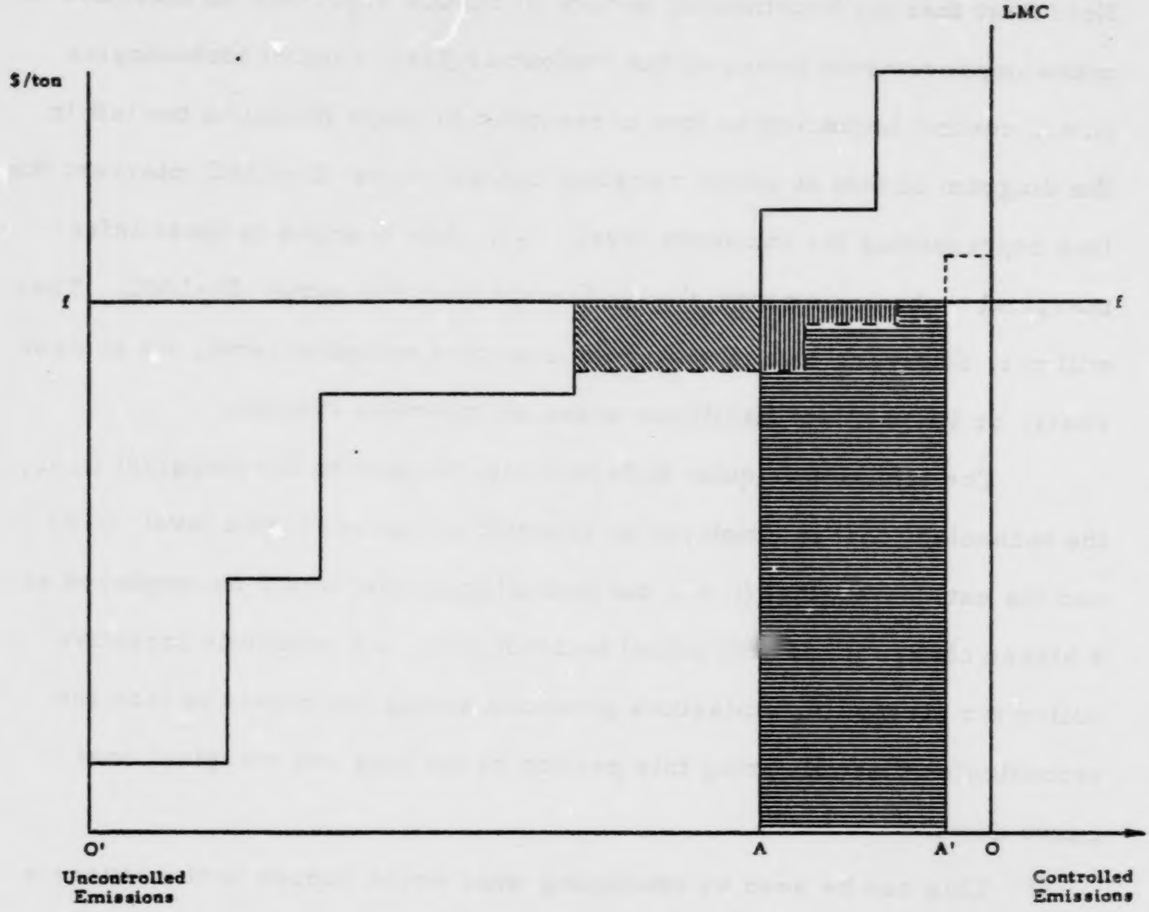
[1] We assume here that the firm is initially at an uncontrolled level of emissions.

Figure 3.5.1

Analysis of Technological Change



permits) are given by the sum of the area under this step function O'-LMC up to A (this gives total control costs) and the area of the rectangle bounded by the lines f-f, O, and A.

This diagram contains all of the basic ingredients we need to understand why it is that an economic incentive policy for pollution control encourages the development of more effective pollution control technology. Note first that the hypothetical source in Figure 3.5.1 has no incentive to make improvements in any of the "inframarginal" control technologies (i.e., control technologies that correspond to steps falling to the left in the diagram of that at which marginal control costs O'-LMC intersect the line representing the incentive level, f-f. Any changes in these inframarginal technologies may change the shape of the curve O'-LMC. They will not, however, change either the source's emission level, its control costs, or its payment liabilities under an incentive system.

The situation is quite different with respect to the marginal (i.e., the technology that is employed to restrict emissions to the level O-A) and the extra-marginal (i.e., the technologies that would be employed at a higher charge or permit price) technologies. An economic incentive policy for controlling emissions produces strong incentives to look for technologies that will bring this portion of the long run marginal cost curve down.

This can be seen by examining what would happen to the source's control costs plus liabilities for payments under the incentive shown in Figure 3.5.1 if the source were able to find new lower marginal cost technologies to substitute for the marginal and the first extra-marginal technologies. Suppose for example that the source found methods that would change the marginal cost curve in the neighborhood of A as shown by the dotted line in Figure 3.5.1. Then the source's control costs plus liabilities for charges or permits would be reduced by the amount of the vertically plus the diagonally shaded areas shown in Figure 3.5.1. This saving is the net result of two effects. First, introduction of the new technologies increases control costs by the amount of the horizontally shaded area in the figure less the diagonally shaded area. Second, increased control reduces liabilities for charge or permit payments by an amount represented by the sum of the horizontally and vertically shaded areas. The net result, as stated above, is a net saving represented by the vertically plus the diagonally shaded areas. This potential savings provides a constant inducement to look for new technology that is lower-cost and more effective than existing technology. It also provides an automatic incentive to use this new technology once it is discovered.

Our analysis above of the two component effects which determine the size of savings realized from the introduction of new technology also shows why it is that regulatory policies fail to provide inducements to technical change. Suppose for example that the hypothetical source shown in Figure 3.5.1 were subjected to an emissions limitation of O-A. Suppose further that it developed the new technologies reflected by the dotted alternative portion of the marginal cost curve, and as a result, was subjected to the more stringent emissions limitation O-A'. [1] The net effect would be to increase the source's control costs by an amount equal to the horizontally shaded portion of the figure net of the diagonally shaded portion. This represents a disincentive to develop or to apply new control technology. [1]

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[1] This could come about, for example, through redefinition of reasonably available control technology, or through a regulatory policy (like enlightened regulation discussed above) that set emissions limitations based on marginal control costs.

Many of today's regulatory programs implicitly recognize the failure of current policy to stimulate sufficient R&D on new emissions control technologies. In an attempt to remedy this deficiency, the government performs or contracts for the performance of a substantial amount of emissions control research and development. This solution (i.e., government sponsored R&D) is inadequate, in our view, in two respects. First, the government does not have the kind of first-hand industry knowledge needed to plan and manage an efficient program of "industry" R&D -- and, for reasons described above, it is in industry's interest to keep the requisite knowledge from the government. At base, this is but one more way in which imperfect information and costly decision-making pose barriers to efficient and effective regulation. Second, even if government sponsored R&D were as efficient and effective in developing new control technology, additional regulatory effort probablv would be required to redefine standards so as to force adoption of the new technology. Recall that, under an economic incentives policy, there are automatic incentives for adoption of new technology.

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[1] If conditions are such that an innovation will save a source money under regulation, then it will go ahead and adopt it. Under regulation, a source might conceivably search out a more effective substitute for the marginal technology shown in Figure 3.5.1. It would not want to go beyond this point, however, and would have cause to fear that if the agency learned of its success in cost reduction, its emissions standard would be made more stringent.

We conclude that, from the perspective of development of new emission control technology, a policy based on economic incentives would outperform even the most sophisticated conceivable regulatory policy. This is, in view of the national importance that justifiably is attached to improved pollution control technology, an important advantage of incentive-based policies. [1]

Our discussion to this point has compared economic policies with regulatory policies. We should note, although we will not analyze it in any detail, that there probably are differences between permit and charges policies (as we have discussed them above) in the stimulus they provide to technical change. The most important point of difference, we believe, arises from the greater certainty about the future that may be provided under a permit policy via options and futures. Under a charges policy, there seems to be no natural comparable way for sources to reduce future uncertainty. If we were to hypothesize that uncertainty about future charge levels tends to reduce investment in control research and development, then we would conclude that investment in emissions control R&D under a permit policy (with futures and options) would tend to be greater than it would under a permit policy.

3.5.3 Adaptability to Inflation and Economic Growth

One frequent criticism of emissions charges is the relative difficulty that is likely to be encountered in attempts to change their magnitude. This means that no matter how the charge schedule is set initially, the system is vulnerable to steady erosion by inflation.[1] For example, if the purchasing power of the dollar falls by, say, six percent per year, an emissions charge of f dollars per pound would also effectively be reduced by six percent per annum.

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[1] New technology facilitates economic growth without sacrifice of environmental standards, or may even make it possible to tighten standards *and* accomodate economic growth at the same time.

A similar problem arises if industrial activity and emissions grow rapidly in an area. In this case, if the inhabitants of the region wish to protect themselves by inhibiting the growth of emissions, the level of charges would have to be increased. Yet, this can be extremely difficult to accomplish politically.

The problems of inflation and growth may be more easily handled by a system of marketable emissions permits as their market price will rise automatically as inflation erodes the purchasing power of the dollar and as growth increases the demand for permits. Thus, there is no reason to expect any erosion in the effectiveness of the permits to control pollution.

In practice, one would expect that if a marketable permit program were to become excessively severe -- if firms were threatened with closure for lack of emissions permits and this caused unemployment and poverty -- the pressures upon the environmental authority would be likely to grow irresistible. Variances may be invoked so polluters can survive, or, as sometimes happens, the regulator may simply be forced to look the other way. In either case, the result would be that the permit system would degenerate into an ad hoc arrangement with the kind of case-by-case decision-making which characterizes the administration of current regulatory policy, and the entire program could be rendered ineffective. This undesirable outcome is often sited as the prime potential weakness of marketable permit systems.

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[1] One method to circumvent this problem would be to index the charges on the basis of, say, cost-of-living increases.

The problems of adapting regulatory policy to inflation and growth are rather different from those faced by incentives policies. Inflation will not erode the effectiveness of emissions regulations. It will, however, alter the cost of complying with regulations and may (if it changes relative prices facing sources) increase or decrease the inefficienty associated with regulation.

As is the case for emissions charges, emissions regulations may have to be changed to accomodate growth. As pressures for location in an ambient air quality region grow, more stringent limitations of emissions from existing sources may be required to maintain ambient standards or to prevent significant deterioration.

There is one additional remark (which is at base, speculative, since we have performed no detailed analysis to support it) that we should make concerning the adaptability of alternative policies to future events like inflation and growth. It seems to us that a marketable permits policy has an edge in accomodating to future events not only in that it adjusts automatically (as we have discussed above), but also in that it provides a natural means (via options and futures markets) for sources to reduce uncertainty about future developments. We think that further analysis would show this in fact to be an important advantage.

3.5.4 Market Imperfections

In an Appendix to this chapter we discuss in detail the effects of alternative market structures on polluters' responses under systems of economic incentives. Here, we shall briefly examine the related issue of how charge systems may differ from permit systems in their effectiveness when markets are imperfect. As noted in Section 3.3.1, a system of emissions charges can, in principle, achieve a specified reduction in emissions at minimum cost to society. One of the important features of this proposition is that it does not require markets to be competitive. [1/] Polluters may be monopolists or oligopolists; they may not even be profit maximizers. As long as they are cost minimizers, the result will hold.

On the other hand, monopoly power may undermine the efficiency properties of a system of permits. For example, when the market for permits is dominated by one or several firms, they can, in effect, tailor their demands so as to rig the permit prices. Specifically, it will be in their interest to deliberately restrict demand in order to force the price of permits lower than it would otherwise be. This is analogous to the situation in which an unregulated monopolist restricts the supply of output in order to force up its price. The result in the case of pollution control will be that incentives will be distorted since the price of permits

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[1/] See Baumol and Oates (1975), p. 125ff.

will be artificially low, and consequently, it will not provide the proper incentives for polluters to restrict emissions.[1]

Even worse problems may arise if markets are imperfect. For example, a large firm may choose to buy more permits than it needs for its own operation in order to inhibit the activities of its competitors. In this case the permits could conceivably become an instrument for restricting competition.

The upshot is that many analysts agree that a system of emissions permits will perform badly in an arena that is characterized by markets that are not sufficiently competitive.[2] In such cases, a system of emissions charges is likely to prove superior.

The practical question is then one of determining: How competitive is "sufficiently competitive?" The history of anti-trust activity illustrates how difficult it is to answer this question. The most that can be done is to structure the market to try to insure as much competition as possible and to make available the remedies provided in anti-trust statutes for prosecution of any who would use monopoly power to restrain trade.

It may seem that the "potential monopoly problem" is associated uniquely with a marketable permit system. While this is true in strictest terms, problems very similar to that described above may arise under an emissions charge system or a regulatory system. Under these latter systems, firms with economic power may use this power (and any associated political power) to coerce a charge-setting or regulation-setting authority.

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[1] Ackerman et al. (1974) remark that although a permits system may provide the opportunity for "buyers" to enter into collusive arrangements to keep prices down, the pollution objectives would still be unaffected if the number of permits was kept the same. However, if one of the goals of the program is to provide incentives for still further improvements in environmental quality, collusive behavior will affect the pollution objectives.

[2] On this, see Nemetz (1977) and Taylor (1975).

3.5.5 Distributional Considerations

Most environmental programs are characterized by a combination of control strategies, with the initial financial burdens shared by various levels of government, industrial sectors, and households. The ultimate distributional consequences of these policies, however, depend upon the way in which these initial financial burdens are shifted to the general population. This shifting, in turn, is dependent upon such factors as government tax structures, relevant market structures, and revenue use (if applicable). It should be clear from this description that predicting and evaluating the distributional impacts of environmental policies will be challenging tasks.

An example may highlight the difficulties. [1/] While it may seem "fair" and may make good economic sense to require the steel industry to pay for its own air pollution control, it is likely that the associated costs of control can be shifted to a large degree to steel customers and, in the long run to final consumers. To the extent that this shifting of costs is possible, the financing of pollution control in the steel industry would take on aspects of a general sales tax, since steel is a major component of a large number of final consumption products. Thus, what at first seemed

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[1/] This example is taken from Peskin (1978).

fair, may in the end appear regressive and unfair, since the poor might bear a proportionately greater share of these control costs. [1]

In the introduction, we noted that good environmental policy should result in higher prices for pollution-producing goods. Is this consistent with the preceding illustration in which higher steel prices may result in a regressive cost structure for financing pollution control in the steel industry? Not necessarily. So far we have looked only at half the picture -- that is, we have concentrated solely on the costs of control. In order to provide an adequate evaluation of the control program, it is also necessary to examine who would benefit from such pollution abatement. For example, if the poor are also the primary "victims" of the steel industry's pollution, they may receive proportionately larger benefits from the policy. [2] Thus, when net benefits are considered, the policy may be judged fair and equitable.

Unfortunately, there have been relatively few attempts to examine the distributional impacts of U.S. environmental policies. One of the few rigorous analyses of this sort was undertaken by Gianessi, Peskin, and Wolff (henceforth, G-P-W), in their examination of the distributional effects of the Clean Air Amendments of 1970.[1] Specifically, they distributed the costs and benefits associated with the uniform air pollution policy in the United States across families located in county groups and Standard Metropolitan Statistical Areas (SMSA's). They then calculated net benefits and disaggregated these by income class and race. Finally, they classified the results by two categories of pollution, the industrial component and the household component (comprised primarily of automobile ownership).

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[1] A tax structure is said to be regressive (progressive) if the share of a taxpayer's income paid in taxes decreases (increases) with his or her income. Similarly, the cost structure of a policy is regressive (progressive) if the share of income allocated to costs falls (rises) with income. On the other hand, the benefit structure of a policy is regressive (progressive) if benefits as a fraction of income increase (decrease) with higher incomes. Finally, we note that the net benefit structure of a policy is regressive (progressive) if benefits minus costs as a fraction of income rise (decline) with higher incomes.

[2] Several studies have concluded that the benefits from pollution abatement are greater for lower income groups. See, for example, Freeman (1972) and Zupan (1973).

Looking at the total air pollution policy (industrial plus household components), they found that the relative burden (costs) fall more heavily on the poor. That is, the cost structure of the policy was found to be regressive. At the same time, they found that the benefit structure was progressive; that is, the rich enjoy fewer benefits per dollar of income than the poor. Overall, net benefits appeared neither progressive nor regressive; they were proportionately distributed for incomes above $10,000. G-P-W noted, however, that there was a large difference in the distributional implications of the industrial component versus the household component of the air pollution policy. Net benefits of industrial air pollution control were positive for almost all income groups and were progressively distributed. On the other hand, net benefits of the automobile pollution policy were negative and regressively distributed across income groups. What these findings suggest is that even if the uniform air pollution regulations treat polluters in a relatively uniform manner, the policy does not treat those affected by air pollution in an equitable fashion.

Whether or not the G-P-W findings can be taken as accurately representing the distributional implications of the current U.S. air pollution policy, our prime concern is how the present distributional effects might differ under alternative strategies of pollution control. In particular, we are interested in predicting changes in the distributional impacts that would occur if an economic approach to pollution control such as a system of emissions charges were implemented.

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[1] See Gianessi, Peskin, and Wolff (n.d.).

As was argued in Sections 3.4.1 and 3.4.2 of this chapter, economic approaches to pollution control such as charge systems and permit systems may be attractive on grounds of economic efficiency. However, it should be recognized at the outset that there is no guarantee that such approaches will be better or worse from an equity standpoint than the current regulatory approach to pollution control. We will illustrate this proposition with a hypothetical example. 1/

Suppose there are two cities, Dirty City and Clean City. Dirty City's industries manufacture a capital good that results in air pollution as a byproduct. At the same time, Clean City's plants use Dirty City's capital good in the production process in order to create a non-polluting final good. The population of both cities consume Clean City's final good. Furthermore, only the residents of Dirty City experience air pollution -- that is, air pollution remains localized in Dirty City. Now suppose Dirty City establishes an economically efficient air pollution policy by instituting a system of emissions charges. It would be expected that the implementation of the charge system would raise the price of the capital good that is manufactured in Dirty City and "exported" to Clean City. In turn, the increased cost of the capital good would presumably

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1/ This example is an adaptation of an illustration presented in Gianessi, Peskin, and Wolff (n.d.).

raise the price of the final good produced in Clean City (and consumed in both areas).

What can be said about the distributional implications of the emissions charge system? A moment's thought leads to the conclusion that depending upon the relative demand elasticities for the two types of goods in the two cities, it is conceivable that Dirty City could shift the cost burden of air pollution control almost entirely to Clean City. The implication of this shifting would be that while in the aggregate the control policy could be economically efficient (aggregate marginal costs equal aggregate marginal benefits), the costs and benefits of the policy might be shared inequitably. In particular, residents of Clean City would be net losers since they had nothing to gain; their air was already clean. At the same time, residents of Dirty City would be net gainers since they had cleaner air and were able to "export" most of the associated cleanup costs.

While the above illustration is greatly simplified and is based upon rather unrealistic assumptions, it does make clear that the distributional impacts of such economic approaches to pollution control can depend upon complex trade and market patterns. Furthermore, there is another related aspect to the type of charge system envisioned in the example. It concerns the fact that if charges are set locally or regionally, the resulting distributional impacts can be considerably different than if charges are set uniformly. For example, it is possible that areas desirous of industrial growth would choose to set relatively low charges to attract new industries. Initially such areas would probably be characterized as high-cost (of abatement), low-benefit (from abatement), since they would be relatively clean and further control efforts would be costly with little return. Under these conditions, with emissions charges low relative to other parts of the country, these areas could change to a low-cost, low-benefit pattern. All this, of course, is speculative. To the extent that the prevention of significant deterioration (PSD) rules apply to such areas, these guidelines act as constraints to this type of distributional change taking place under a system of emissions charges.

As noted earlier, the equity aspects of an emissions charge system will also depend upon how the generated revenues are used. What can we say about alternative uses of charge revenues and their distributional impacts?

It may be true that if the purpose of an emissions charge system is to bring about approximately the same emissions reductions that are the targets of the current regulations, then the distributional implications of such a system would not be very different than those under the present strategy. However, in making this argument, it is important to realize that if the charge system is, indeed, more efficient than currently mandated control efforts, than this implies that total pollution control costs should be lower and there is at least the potential for net gains under the charge system. This is directly related to what Gordon Tullock calls the "excess benefit" associated with emissions charge systems. [1]

Briefly, Tullock first notes that if an activity imposes an external social cost (such as air pollution damages), then a properly calculated emissions charge system can bring marginal social costs in balance with marginal social benefits. Furthermore, he argues, that the revenue generated by the charge payments can be used to provide benefits in "excess" of those associated with emissions reduction. Thus, a system of emissions charges has the potential for not only improving general well-being (by reducing pollution), but also generating funds that can be used to provide "excess benefits."

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[1] See Tullock (1967)..

If, for example, charge revenues were used for general tax relief, this would add some degree of regressivity to the pollution control policy, since the wealthy bear a relatively larger proportion of tax burdens. 1/ The effect would thus would be to reduce the tax burden on the wealthy. If, on the other hand, charge revenues were used to subsidize publicly owned pollution control facilities, this would add a measure of progressivity to the policy. This follows from the presumption that such facilities would substitute for private (industrial) pollution control facilities. 2/ An even more progressive outcome might take place if charge revenues were targeted directly for subsidies to low income populations.

Thus, the distributional implications of targeting charge revenues to alternative purposes should be kept clearly in mind when designing economic approaches to pollution control. With that said, however, it is difficult to offer concrete methods for accomplishing this. As shown, it is exceedingly difficult to determine the distributional impacts of environmental control policies. In the end, it is probably the case that the decision to implement an economic approach to pollution control will have to be made independently from considerations of more than first-

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1/ See E. Browning (1978).

2/ The reader is referred back to the earlier arguments made in connection with the steel industry example. See page 3-48.

order distribution. Nevertheless, it is important to reiterate that to the extent that such a system were intended to meet current emissions goals, the distribution effects would presumably not differ greatly from those under the current approach. To the extent that they did, the system would have the potential of offsetting adverse effects by virtue of the "excess benefit" argument.

In theory, the effects on income distribution of a system of permits or a system of emissions charges should be precisely the same if they both bring about the same level of pollution control. For example, if one assumes that all markets are perfectly competitive and that one desires to reduce the quantity of NO_x emissions in the atmosphere by X percent, then if this is achieved by either of the two mechanisms, it will be done via an increase in the "real" cost of emissions, either through a direct charge or through the market price of a permit. In either case, the equilibrium rise in emissions costs will be the same. Furthermore, the resulting shifting and incidence will be the same and will depend upon the progressivity or regressivity of the charge schedule or permit price structure. This, in turn, will depend upon the commodities and services whose production or consumption produces emissions. 1/

In practice, things are more complex. First, a system of permits is not likely to work identically to a system of charges. For example, we have discussed above that a system of charges may be eroded by inflation and that a system of permits may hamper economic growth. Thus, one

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1/ Information on this subject is quite imperfect, although there is evidence that the results are likely to be regressive.

might expect that the passage of time would weaken the distributive effects of a charge system while enhancing those of a permit system.

A second difference in distributive effects is likely to arise because of market imperfections influencing the market for permits. As noted above, this problem is less relevant to a system of emissions charges. Thus, if such distortions do occur, one would expect a shift in the cost of permits from those who exert such influence, with the burden being shifted to the general public. As a consequence, a system of permits may prove more regressive than a system of emissions charges.

There is yet another possibility that works in the opposite direction. Suppose that both systems are judged to be inherently regressive. Then a system of permits offers a means to offset this effect, while a system of charges does not. For example, assume permits were required for all polluters in an area. Assume further, that such permits were provided initially free of charge. Then, if a market in permits developed, those with incomes below average might well choose to use only a portion of their permits and sell the remainder on the market. This could have the effect of offsetting any initial distributional consequences that increased the inequality of incomes.

3.5.6 Other Issues

When emissions are difficult to observe and monitor, neither emissions charges nor emissions permits may be practical. For example, it is useless to offer for sale a permit authorizing no more than X units of emissions per day if no one knows whether the polluter is producing half or twice this amount on any given day. In such cases, direct controls that require the installation of specific control devices, or that prohibit particularly polluting processes, or that limit the use of polluting inputs may be the only feasible option available. [1]

Similarly, small polluters whose emissions are costly to monitor relative to the damage they inflict may also require direct controls. In these cases, permits or charges might still be used for large polluters. [2] Although as discussed above, this could seriously affect the competitiveness of the market under a permit system.

Finally, episodic pollution emergencies may provide problems for the use of charge or permit systems. This follows, since it is relatively difficult to reduce sharply the number of permits or to alter a charge schedule in a short period of time. Thus, in such cases, it may be preferable to impose direct controls requiring the reduction or cessation of specific activities. Baumol and Blackman (1978) do note, however, that a permits market may be more adaptable to the problem than a system of emissions charges since one can operate a permit system in which two classes of permits are available -- interruptible and noninterruptible. The former would have a lower market value and would be subject to being declared inoperative by the environmental authority, say, for a maximum of X days per year, upon h hours notice. On the other hand, firms would purchase noninterruptible permits for operations that were considered vital. [1]

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[1] Stephenson (1977) points out a number of pollution control situations in which economic incentives do not apply or in which their advantages are weak. For example, he notes that when non-point sources of pollution are a problem as in the case of pesticide runoff from farmlands involving numerous unidentifiable sources, a tax on input (pesticide) usage may be the only viable solution.

[2] Mar (1971) proposes a permit system that includes "major" rights and "minor" rights, in which major rights are acquired by large institutions (such as municipal power plants or sewage authorities) and would allow a unit change in air or water quality within a specified zone, and minor rights are acquired by individuals or small institutions and would have a negligible impact on environmental quality. He further postulates that owners of major rights could subdivide and allocate subrights within their zones (subrights could be defined in terms of allowable emissions rather than on the basis of changes in air or water quality). Holders of major rights could also levy surcharges to monitor and administer subrights.

3.6 Conclusions

While the discussion in the preceding sections of this chapter is wide ranging and leads to several interesting conclusions, two major practical conclusions for public policy can be drawn. The first is that economic incentives provide a policy instrument that results in efficient (i.e., low cost) and effective (i.e., ambient air quality consistent with ambient constraints) improvement of the environment. Several reasons support this conclusion, including the facts that economic approaches (1) automatically tend to equate abatement costs at the margin -- a necessary condition for efficient pollution control, (2) provide a continuous incentive for environmental improvement, and (3) provide a continuous incentive to search for cost-reducing technological improvements in emissions control.

Many have argued, as we discussed in this chapter, that an improved or enlightened form of regulation, designed and administered so as to minimize costs, could also achieve efficient and effective abatement of air pollution. Analysis of this argument leads to our second major conclusion. In particular, we find that, due to uncertainty and assymetry of information, even enlightened regulation will not be as efficient nor necessarily more effective than a system of economic incentives.

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[1] Mackintosh (1973), in his hypothetical "Regional Air Rights Exchange" (RARE) for New Orleans, proposed a plan for dealing with atmospheric inversions: RARE would (under a pre-announced plan for emergencies) declare that all permits were worth one-tenth their normal contaminant value and that the price per permit would be frozen at the going market price for the duration of the inversion. Polluters wanting to continue normal operations would have to purchase ten times the usual number of permits. He concludes that the number of permits available during an inversion would rapidly approach zero and that emissions would not pose a health hazard.

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APPENDIX TO CHAPTER 3

MARKET STRUCTURE CONSIDERATIONS

1. Introduction

The analysis of economic incentive systems to control pollution typically is carried out in a theoretical framework of profit-maximizing firms operating in competitive markets. For example, the establishment of the optimality properties of emissions charges usually depends upon this framework and on a number of other fairly restrictive assumptions. Yet, a cursory inspection of the real world, reveals that the major sources of pollution encompass a wide variety of institutional structures. The public sector, for example, is itself a major polluter. 1/ Municipal waste-treatment plants dump enormous quantities of wastes into our waterways, and publicly owned power plants are heavy contributors to air pollution. The largest single sulfur polluter in the United States is the Tennessee Valley Authority (TVA), which alone accounts for 16 percent of sulfur emissions in the nation. 2/ In addition, private, but publicly regulated, firms (including utilities that provide electrical power) are among the very largest of polluters. Finally, many of the large factories that emit massive quantities of wastes into the nation's waterways and atmosphere are owned and operated by huge firms in highly concentrated industries such as steel, chemical, and automobile. The application of the competitive model with its myriad of small firms acting as price takers is therefore suspect for many classes of polluters and raises

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1/ On public-sector pollution, see Oates and Strassmann (1977).

2/ See King (1977).

important questions concerning both the effectiveness and efficiency of economic incentive systems under alternative market structures.

With regard to effectiveness, there is some concern that polluters will not respond to incentives and that emissions controls necessary for the attainment and maintenance of ambient standards will not be forthcoming. For example, there is some fear that firms that are protected from competition such as regulated utilities would simply pass charges along to their customers without attempting to reduce emissions.

With regard to efficiency, there is concern that incentives applied to markets in which there are important imperfections will lead to worse rather than better resource allocation. While the most general demonstrations of this point are contained in the literature on what is known in technical terms as the "theory of the second best," specific theoretical investigations of this problem have been made by Buchanan (1969) and Smith (1976). These investigations have found that total social costs of control may be higher under an economic incentive system than under a regulatory system. Clearly, the implication is that the economic analysis of market incentives for pollution control must push beyond the simple competitive model. We must ask how polluters with widely varying sets of objectives are likely to respond to these incentives and what effect these responses will have on resource allocation and the protection of the environment.

2. Analytical Models

For purposes of the analysis, four different classes of polluters are identified: (1) Competitive (profit-maximizing) firms; (2) Monopolistic firms; (3) Public bureaus; and (4) Regulated firms.

The competitive profit-maximizing firm will serve as a benchmark for purposes of comparison. The second class of polluters, monopolistic firms, refers to producers whose decisions have some effect on the price they receive in output markets. Under this class, both imperfectly competitive, but profit-maximizing, firms and those that pursue some form of "satisficing" behavior will be examined.[1/] To analyze the third group of polluters, public bureaus or agencies, a variant of the Niskanen model of bureaucratic behavior will be employed.[2/] Finally, the standard Averch-Johnson model of the regulated firm will be adopted to explore the likely response of this fourth class of polluters to a system of incentives. From these various "case studies," we shall attempt to construct a more comprehensive view of the impact of a set of market inducements for the control of polluting activities.

We analyze the responses of the four classes of polluters under two analytical frameworks. The first, and more limited perspective, involves the so-called "standards-and-charges" approach.[3/] Here, the environmental authority seeks to achieve a predetermined standard for environmental quality by implementing a system of emissions

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[1/] Satisficing behavior is any kind of behavior that does not seek profit maximization, but rather only satisfactory profits. With regard to this latter behavior, one notable example is embodied in Baumol's sales-maximization hypothesis. See Baumol (1959).

[2/] This model postulates that public officials maximize an objective function that contains as arguments their bureau's level of output and the level of "perquisites."

[3/] See Section 3.4.1 of this report, page 3-10.

charges. The problem of attaining the standard becomes one of cost effectiveness: the realization of the standard at minimum abatement costs.[1] From this perspective, the least-cost solution is obtained when all polluters adjust their abatement efforts such that the marginal costs of abatement are equalized. The second, and broader perspective is the conventional Pareto-optimality criterion with full allowance for all the various effects of emissions charges on the pattern of resource use. Here, we are concerned not only with the resource costs of abatement, but also with the impact of the system on such items as monopolistic levels of output, and other types of market distortions.

Note, that we are not explicitly analyzing the effects of alternative market structures under a system of emissions permits. However, from a formal perspective, in a world of perfect information with no risk or uncertainty, the sale of emissions permits is equivalent to a system of emissions charges.[2] Thus, under these conditions, the analyses that follow should be fully applicable to both types of economics incentives for controlling pollution.[3]

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[1] "Costs" is used here in the restricted sense of the direct resource costs of abatement activities and it ignores the possible indirect costs associated with changing levels of outputs and consequent market distortions. Thus, the concern is solely with minimizing the direct resource costs of abatement activities.

[2] The interesting and important distinctions between the two systems arise with the introduction of uncertainty and with the imposition of various institutional and administrative constraints. For discussions of these issues, the reader is referred to Chapter 3, Section 3.5.1, pages 3-28 to 3-37.

[3] Nevertheless, it is important to recognize that for the equivalence to hold, public bureaus and regulated firms must be treated in the same manner as private firms under a permit system. That is, they must bid for permits on the same terms as private firms.

2.1 Competitive (Profit-maximizing) Firms

As discussed in Chapter 3, under a regime of profit-maximizing firms, the establishment of a charge at the level sufficient to reduce aggregate emissions by the amount necessary to meet a given standard will also generate the least-cost pattern of abatement quotas among firms. Conceptually, this requires no information concerning cost functions on the part of the environmental authority;[1] the latter would simply adjust iteratively the charge to the point where total emissions fall to the level consistent with the environmental standard. At the same time, adjustments by individual firms lead automatically to the least-cost allocation of abatement levels among firms.

From a practical standpoint, iterative adjustment of charge levels is costly and can make the system unworkable. Furthermore, there is another important qualification to the results.[2] The proposition assumes that a unit of emissions degrades the environment by the same amount irrespective of the location or time it is emitted. This obviously need not be the case. For example, a factory spewing a given quantity of nitrogen oxides into the air will likely have a more deleterious effect on air quality it it is located to the windward side of an air shed instead of to the leeward side, or if it has a short stack rather than a tall one. To achieve a given environmental quality standard at least cost, requires that the charge be applied to the effect of the emissions on environmental quality, not just to the quantity of emissions. As we shall see in subsequent chapters, this may be accomplished by means of a schedule of charges that differentiates between zones of emissions or perhaps according to such parameters as the heights of stacks. However, where much finer distinctions seem necessary, the proposal admittedly loses some of its simplicity.

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[1] Information concerning abatement costs can be quite useful to the environmental authority since it permits the determination of an initial fee that is relatively close to the ultimate fee so as to hold down the costs of adjustment.

[2] On this qualification, see Teitenberg (1974) and Rose-Ackerman (1973) .

There are some other important caveats. As with most other results in economic theory, this proposition assumes no distortions elsewhere in the economy. This assumption is of special importance in the case of externalities because the presence of external effects raises the likelihood that second-order conditions will be violated. In particular, one can unequivocally state that, if the external effects are of "sufficient magnitude," the second-order conditions for Pareto-optimality will not hold. [1] In simple English what this all translates to is that if market imperfections or distortions are too great, then the implementation of a system of charges may make the situation worse. For example, it might induce an even more inefficient locational pattern of polluting and nonpolluting activities.

2.2 Monopolistic Firms

The introduction of imperfectly competitive firms into the marketplace need not invalidate the optimality properties of instituting an emissions charge system to control pollution. For example, in considering a profit-maximizing monopolist, one need only note that profitmaximization implies (as in the competitive case) that pollution abatement will be extended to the point where marginal cost of control equals the emission charge. Therefore, since polluters will be setting marginal abatement costs equal to the same charge, the least-cost property of the standards-and-charges approach is assured.

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[1] See Baumol and Oates (1975), Chapter 8.

The nature of this result makes clear the further point that the least-cost solution does not require profit maximization, but only cost minimization. This means that various types of satisficing behavior are consistent with the least-cost pattern of abatement costs so long as they imply cost minimization by individual firms. For example, a firm that seeks to maximize its revenues subject to a minimum-profit constraint is still a cost minimizer; in consequence, it causes no problems for the least-cost result. The upshot of all this is that, even if the economy is composed of some mixture of perfectly competitive firms, profit-maximizing monopolists, and sales-maximizing oligopolists, the standards-and-charges technique will theoretically achieve a predetermined set of environmental quality standards at the minimum total abatement cost. Despite this conclusion, imperfectly competitive market structures can create problems.

Consider the case of a profit-maximizing monopolist.[1/] The basic dilemma results from the monopolist's suboptimal level of output. An emissions charge provides an incentive for needed pollution abatement, but at the same time, it raises the firm's marginal costs and thereby induces a reduction in output. The result is some gain in efficient

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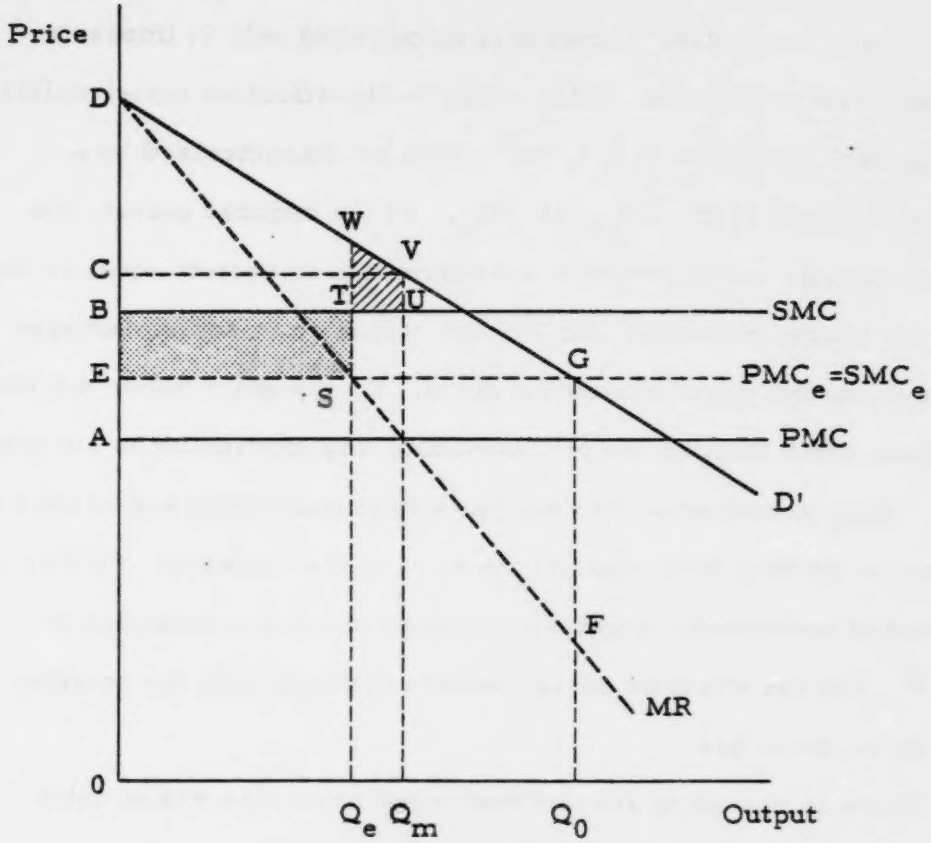
[1/] See Buchanan (1969) and Baumol and Oates (1975). The treatment here follows that in Baumol and Oates, who (unlike Buchanan) allow for pollution abatement technology. Buchanan assumes a fixed external cost per unit of output.

resource allocation from reduced waste emissions, but some loss in efficiency from the contraction of output. The emissions charge, while reducing the social costs of pollution, simultaneously increases the welfare loss resulting from excessively low levels of production, so that the net effect on social welfare is uncertain.

The nature of this trade-off is apparent from Figure 2.2.1. Let DD' represent the industry demand curve confronting the monopolist, with DMR being the corresponding marginal-revenue curve. Assume that the monopoly can produce at constant cost (PMC = private marginal cost), but that its production activities impose costs on others. In particular, in the absence of any fees, the monopolist's (private) cost-minimizing technique of production generates pollution costs per unit equal to AB so that the SMC (social marginal cost) curve indicates the true cost to society of each unit of output. To maximize profits, the monopolist would produce OQ_m .

Suppose that the monopolist is then subjected to an emissions charge per unit of emissions. This will provide an incentive to alter the production process in a way that yields lower emissions per unit of output. In Figure 2.2.1, this would have two effects: it would raise the PMC curve and, over some range, would tend to lower SMC. This second effect results from the choice of what from society's standpoint is a lower-cost method of production (taking into account the social costs of pollution). The minimum social cost of production will be reached when the pollution costs are wholly internalized so that $PMC_e = SMC_e$ (where the subscript e refers to costs in the presence of an emissions charge). At this point, the firm's selection of a production process will be based upon a set of input prices (including a price of waste emissions) that reflects true social opportunity costs.

Figure 2.2.1



Source: Baumol and Oates (1975), p. 72.

In Figure 2.2.1, the optimal output is OQ_o , which is produced at the least social cost. To achieve this optimum requires two policy actions: an emissions charge on waste emissions in order to reduce SMC to SMC_e and a subsidy per unit of output equal to GF (the difference between marginal cost and marginal revenue at the optimal level of output). Because there exist two types of distortions, full correction generally requires two policy instruments.

Unfortunately, a regulatory agency does not typically have either the authority or the inclination to offer subsidies to monopolies. Suppose, more realistically, that it is empowered only to impose a charge on waste emissions. What would be the effect on social welfare? Referring back to Figure 2.2.1, this would be characterized by a reduction in output from OQ_m to OQ_e. At the reduced output, the emissions charge would generate a welfare gain to society equal to the area of the shaded rectangle EBTS: the reduction in social damages to the environment net of abatement costs. On the other hand, the increase in marginal costs induces the profit-maximizing monopolist to cut output to OQ_e which accentuates the original suboptimal output and results in an additional welfare loss equal to the area of the trapezoid TWVU: this is the loss in consumers' surplus resulting from the contraction in output. [1] The net effect on social welfare depends upon the relative size of these two areas.

There is reason to suspect that these two areas are of quite different orders of magnitude. That is, there is evidence that the gains resulting from internalizing the social costs of pollution may be quite different than the welfare loss associated with the further contraction of monopoly output. For example, there are several rough estimates of the social gains from pollution abatement that suggest that these benefits are quite large.[1] In contrast, Harberger's estimates of the welfare losses associated with monopolistic restrictions of output suggested a smaller effect.[2] If these estimates are correct, then the ambiguity introduced by monopolistic distortions may be of little practical importance in considering the application of emissions charges to pollution control. Below, some crude estimates of the orders of magnitude involved are presented.

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[1] Income effects are being ignored and only the vertical distance to the demand curve is being used as a measure of social marginal valuation. Note, the change in welfare associated with the reduction in output need not be negative. If the external cost per unit exceeds the difference between price and marginal revenue, a reduction in output will increase welfare.

The size of the two effects depends upon a number of key variables. These include the magnitude of the charge, the level of marginal social damages (costs), and the price elasticity of demand for the final output. More specifically, the two areas depicted in Figure 2.2.1 can be approximated by:

$$\text{EBTS} \equiv \Delta W_g = Q(\text{SMC} - \text{SMC}_e) \tag{2.2.1}$$

$$\text{TWVU} \equiv \Delta W_\ell = \Delta Q(P - \text{SMC}) \tag{2.2.2}$$

where ΔW_g is the welfare gain associated with pollution abatement and ΔW_ℓ is the welfare loss associated with reduced output (the other variables being defined above).

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[1] These gains may take either of two forms. The first concerns the benefits (reduced damages) associated with pollution abatement. The second involves the cost savings associated with using economic incentives to control pollution and internalize social costs. On the first issue, see Lave and Seskin (1977); on the second, see Kneese et al. (1971) and Bingham et al. (1974).

[2] See Harberger (1954).

To determine the relative sizes of the two effects (ΔW_r), we divide (2.2.2) by (2.2.1) to obtain:

$$\Delta W_r = \frac{\Delta Q}{Q} \frac{(P - SMC)}{(SMC - SMC_e)} \tag{2.2.3}$$

It will facilitate the numerical comparisons to divide both numerator and denominator by P:

$$\Delta W_{r/p} = \left(\frac{\Delta Q}{Q}\right) \left[\frac{(P - SMC)/P}{(SMC - SMC_e)/P}\right] \tag{2.2.4}$$

The next step involves making educated guesses as to the orders of magnitude of the various terms in Equation (2.2.4). In doing so, we will attempt, at each step, to make estimates that are relatively generous with respect to the size of the welfare loss resulting from reduced output. In this way, the result can be regarded as an upper bound for the relative magnitude of the net effect.

First, note that the percentage change in quantity ($\Delta Q/Q$) will depend upon the values of two other variables: the percentage change in price (represented by $\Delta PMC/PMC$) and the price elasticity of demand (ϵ_d). For various polluting industries, there are available estimates of the increases in costs and prices associated with the abatement necessary to achieve U.S. environmental standards. These generally range from about 1 percent to about 10 percent. 1/ The price elasticity of demand will also vary among industries. For the major industries of concern, such as power generation, chemicals, pulp and paper, a typical value of unity is probably a generous assumption. 2/ Thus, as an estimated range for the percentage change in quantity, one obtains:

1/ See, CEQ (1972), pp. 269-301.

2/ See, Harberger (1954).

(2.2.5) $$\frac{\Delta Q}{Q} = \left|\epsilon_d\right| \frac{\Delta PMC}{PMC} = 0.01 \text{ to } 0.1$$

Turning next to the term (P - SMC) in the numerator of Equation (2.2.4), one notes that this quantity is equal to that portion of the difference between price and private marginal cost that is not offset by the marginal social damage (MSD) of waste emissions. Thus, we obtain:

(2.2.6) $$\frac{(P - SMC)}{P} = \frac{[P - (PMC + MSD)]}{P}$$

Note that MSD is marginal external cost equal to AB in Figure 2.2.1.

Finding appropriate values for the variables in Equation (2.2.6) is a bit more conjectural. However, one can make a very rough guess by noting that some estimates of the benefits from air pollution abatement in the United States are about twice the level of abatement costs. Lave and Seskin, for example, offer a conservative estimate of $16.1 billion per year in terms of health benefits alone from meeting EPA standards for controlling particulates and sulfur oxides as compared to EPA's estimate of $9.5 billion for corresponding abatement costs. [1]

Recalling that estimated abatement costs and the associated rise in prices in polluting industries range from one to ten percent of output price, one notes that MSD can range up to 20 percent of output price depending upon whether or not the industry is a heavy polluter. In the case in which the industry generates a substantial quantity of damaging waste emissions, it is difficult to believe that (P - SMC) is very large.

1/ See Lave and Seskin (1977), p. 230. A somewhat higher estimate of damages of $41 billion per year has been advanced recently by researchers at the University of Wyoming. See "Methods Development for Assessing Air Pollution Central Benefits," Vol. V, EPA-600/5-79-001.

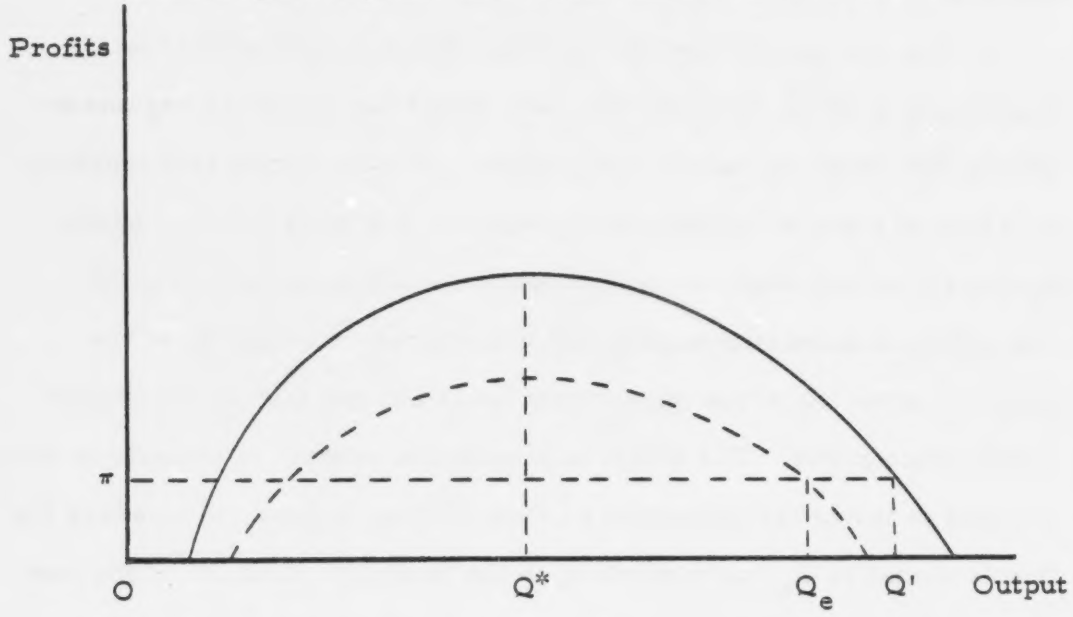
For example, if the industry's markup over private marginal cost (measured in economic terms) is as high as 20 percent, then most of this markup is likely to be offset (or more than offset) by MSD. Thus, we shall assume that a generous value for (P - SMC) is about 0.1.

The denominator of Equation (2.2.4) will also vary with the extent of pollution damages generated by the industry. If, indeed, the benefits from abatement are roughly double the costs of abatement, then for a heavily polluting industry, the reduction in social marginal costs associated with abatement can run from 10 to 20 percent of output price. Taking the lower figure as a typical value, this means that the numerator and denominator of the second term in Equation (2.2.4) are of roughly the same order of magnitude. This, in turn, implies that the size of the welfare loss from restricted output relative to the welfare gain from abatement is of the same general magnitude as $(\Delta Q/Q)$. Thus, according to Equation (2.2.5), the welfare losses are likely to range from only one to ten percent of the welfare gains. As alluded to above, the welfare gains from abatement appear to dwarf the welfare losses from monopolistic distortions.

If this conclusion is placed in the context of the policy options available to the environmental authority, it suggests that, in general, the issue of monopolistic output distortions should be ignored in considering the application of a system of emissions charges. It is doubtful that the authority would be able to vary the charge schedule according to market structure. Therefore, the most likely option involves a discriminatory system of direct controls in which the environmental agency would attempt to tailor individual pollution permits to take account of market structure. Yet, as we have seen from the analysis above, the potential gains from a discriminatory permit system would not appear to warrant such a cumbersome process with all of its attendant inefficiencies.

Figure 2.2.2

Satisficing Monopolist with Minimum-Profit Constraint



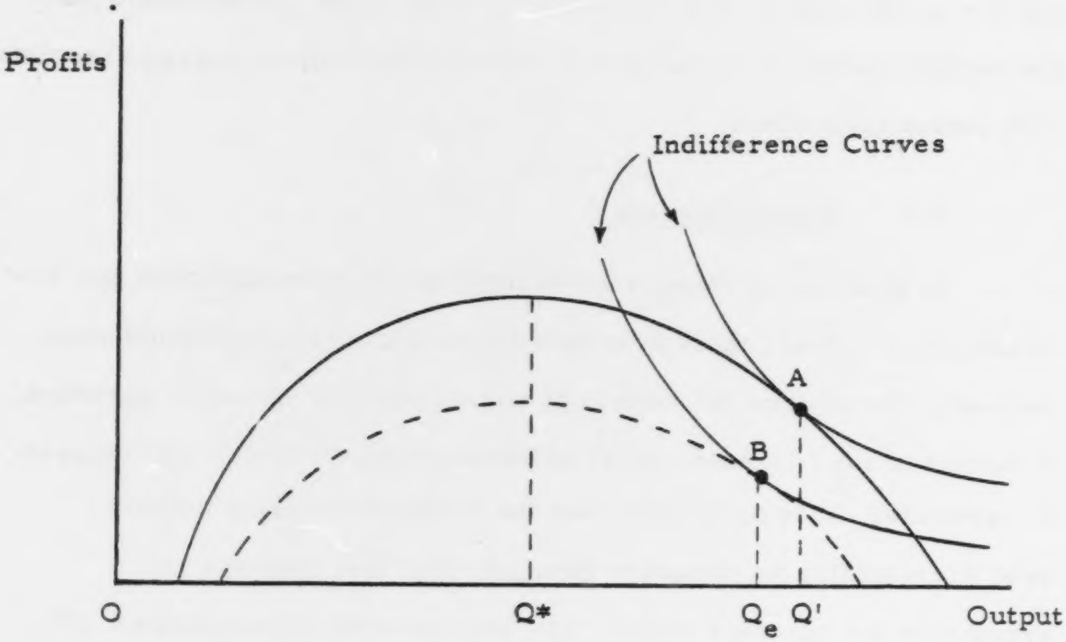
The issue of monopolistic distortions is altered significantly if the monopolist, rather than maximizing profits, adopts some kind of satisficing behavior. Consider the case of a producer who maximizes output subject to a minimum-profit constraint (π). Figure 2.2.2 depicts the equilibrium solution. Instead of producing the profit-maximizing level of output (Q*), the monopolist reduces price and increases output to Q'. The monopolist essentially trades off profits for a larger output until meeting the minimum profit constraint.

While the satisficing monopolist produces more than the profit-maximizing monopolist, it is unclear whether or not the former's output is below, equal to, or larger than the socially optimal output level. What is clear is that the imposition of an emissions fee will lower the opportunity locus and, in Figure 2.2.2, this will reduce the firm's output to Q_e. Depending upon the particular circumstances, this could move the firm's output either toward or away from the socially optimal output level.

One can generalize this by considering a monopolist that maximizes a utility function with both output and profit as arguments. Making the usual curvature assumptions, one can depict this function in terms of a set of indifference curves as in Figure 2.2.3. Again, the purely profit-maximizing monopolist would produce output Q^*. The utility-maximizing monopolist would produce output Q' at the tangency point (A) of the opportunity locus and the highest attainable indifference curve. The effect of imposing a system of emissions charges is again to lower the opportunity locus. This, in turn, will reduce the firm's output to Q_e corresponding to the tangency point (B) of the new opportunity locus with the highest feasible indifference curve. As long as both profit and output are "normal" goods, the solution under the system of charges will entail a reduction in output (as the monopolist attempts to recoup part of the lost profits). However, again, it is not possible to reach unambiguous conclusions as to the direction of change in social welfare, since one cannot determine the positions of Q' and Q_e relative to the socially optimal output level.

Figure 2.2.3

Utility-Maximizing Monopolist



Thus, for the case of a satisficing monopolist, one can only conclude that the implementation of an emissions charge system will bring some welfare gains from pollution abatement. However, the effect on social welfare resulting from the altered level of output may be positive or negative. It is no longer certain that the emissions charge "pushes" output in the wrong direction. While it is true that the net effect is still indeterminate, for the same reasons presented for the profit-maximizing monopolist, there is the presumption that the welfare gains from abatement outweigh the welfare losses associated with output distortions.

2.3 Public Bureaus [1]

In general, bureaucrats are neither profit maximizers nor cost minimizers. Thus, their response to pricing incentives would seem unclear. To explore the impact of emissions fees on public agencies, a variant of the Niskanen model of bureaucratic behavior will be used. In particular, it is postulated that the bureau's decision makers seek to maximize an objective function (U) that contains as arguments the bureau's output (Q), and its level of perquisites (P):

$$U = U(Q, P) \tag{2.3.1}$$

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[1] This section draws heavily on Oates and Strassmann (1977).

Bureaucrats desire an increased output (or "size"), for this enhances the bureau's power and prestige -- its capacity to influence the course of events. However, at the same time, Migue and Belanger have contended that agency officials place a premium on the bureau's "discretionary budget," the excess of the bureau's funding above its necessary costs; this "fat" in the budget can be employed for a variety of perquisites ranging from higher salaries and expanded staff to additional facilities or, perhaps, reduced effort. [1]

Assume, for simplicity, that the bureau produces its output with only two inputs: labor (L) and pollution emissions (E):

$$Q = Q(L, E) \tag{2.3.2}$$

If, for example, output is held at some given level, then pollution emissions can be reduced (or recycled) by employing additional labor.

Assume, further, that the bureau is subject to the following budget constraint:

$$B = wL + fE + cP, \tag{2.3.3}$$

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[1] See Migue and Belanger (1974).

where B is the bureau's budget, w is the wage rate (given to the bureau), f is the emissions charge per unit of pollution emissions, and c is the (constant) marginal cost of perquisites.

There remains the problem of the budget-determination process. Here, it shall be assumed that the bureau negotiates with the legislature for an appropriation that specifies both the bureau's budget and its level of output. Thus, for a given time period, B and Q are predetermined by the legislative budget process; they are not decision variables for the bureau and can be considered as fixed: B_o and Q_o.

With output predetermined, the bureaucrat's maximization problem becomes that of maximizing perquisites (P) subject to the bureau's production and budget constraints. Forming the Lagrangian:

$$L = P + \lambda_1[Q_o - Q(L, E)] + \lambda_2(B_o - wL - fE - cP) \quad , \tag{2.3.4}$$

where λ_1 and λ_2 are the Lagrangian multipliers. Maximizing (2.3.4) and solving for the first-order conditions yields:

$$\frac{MP_E}{MP_L} = \frac{f}{w} \quad , \tag{2.3.5}$$

where MP_E and MP_L represent the marginal products of emissions and labor, respectively. Thus, Equation (2.3.5) indicates that the utility-maximizing bureau satisfies the same first-order condition as a cost-minimizing firm: it sets the ratio of marginal products of the inputs to the ratio of their (given) prices.

The interpretation of Equation (2.3.5) may seem a bit surprising at first since it indicates cost-minimizing behavior despite the fact that the bureau is not, in general, a cost minimizer. The resolution of the apparent paradox is quite straightforward, once it is recognized that Equation (2.3.5) implies cost-minimization in only a limited sense, that is, it states that the bureau minimizes pollution abatement costs. It does this in order to maximize perquisites. Emissions charges are effectively lost dollars; they provide no direct utility to the bureaucrat. However, it is in the bureau's interest to minimize its abatement costs so as to maximize the remaining budget for "procurement" of perquisites.[1/]

What is important for our purposes, is that the bureau is a cost-minimizer with respect to pollution abatement. Similar to private firms, it has an incentive to extend pollution abatement activities to the point at which marginal abatement cost is equal to the emissions charge. This suggests that the least-cost theorem for the standards-and-charges approach can be extended to encompass utility-maximizing bureaus.

There is, however, an important qualification to this finding. Thus far, it has been assumed that the bureau seeks to maximize its perquisites subject to legislatively determined budget and level of output. If, however, a basic perquisite is "ease of management," it is conceivable that the bureau might employ some of the "fat" in its budget to avoid the effort and possible complications associated with the adoption of new abatement techniques. It is difficult to assess how important this qualification is, but it could, in some instances introduce inefficiencies into a system of economic incentives for pollution control. Nevertheless, the analysis above, does suggest that there exist real incentives for

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[1/] We assume here that the budget is fungible between pollution expenditures and perquisites.

bureaucrats to economize on abatement costs. This, in turn, is quite encouraging, for it points to a positive response on the part of public agencies to the implementation of pricing incentives.

What can be said about other effects that might accompany the application of economic incentives to public bureaus? First, it is important to note that most models of bureaus (including the one presented above) imply unambiguously that the bureau's equilibrium output will exceed the socially desirable level. 1/ The rationale behind this is simple: since bureaucrats are typically assumed to maximize an objective function containing as arguments their budgets or outputs as well as other variables such as perquisites, they can effectively trade off part of the "fat" in their budgets for increased size. This, in turn, implies that bureaucrats will use some of their "surplus" to produce additional units of output for which the corresponding marginal cost exceeds the marginal value to society.

A system of emissions charges, by increasing the bureau's costs of operation, can be expected to have some impact on its level of output. The effect of introducing such a system would be to raise costs and "eat" into the bureau's fat. This, in turn, would reduce the bureaucrat's capabilities of generating excessive output or perquisites. From this perspective, emissions charges for pollution control can generate some beneficial side effects in terms of both reducing the extent of excess production and lowering the bureau's cost for any given level of output. Thus, emission charges on public bureaus have the potential for increasing social welfare in three distinct ways: reduced pollution, a lower level of "excess production," and a lower cost per unit of output.

1/ For a useful survey of models of bureaucracy, see Orzechowski (1977).

2.4 Regulated Firms

The presence of regulated firms introduces serious complications for the minimization of pollution abatement costs.[1] Such firms are not, in general, cost minimizers with respect to production inputs. Hence, one would not expect them to respond to pricing incentives for pollution control in a cost-minimizing fashion. The source of the difficulty is that the regulatory constraint effectively distorts the relative prices of inputs to the firm such that cost minimization from the firm's perspective involves an excessive use of capital. This inefficient resource allocation is referred to as the Averch-Johnson (A-J) effect. By overutilizing capital, the firm is able to enlarge the base upon which its regulatory constraint is determined. At the same time, the firm has no incentive to control emissions to the point at which marginal abatement costs are equated with an emissions charge.

To explore the behavior of regulated firms more formally, a variant of the standard A-J model will be used; the extension involves including pollution emissions as a factor of production. The analysis will focus on two cases: a profit-maximizing regulated firm and a revenue-maximizing regulated firm.

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[1] "Regulated firms" refers here to private firms whose earnings are limited to some maximum "fair" rate of return to capital inputs. For excellent, comprehensive treatments of the analytics of the regulated firm, see Baumol and Klevorick (1970) and Bailey (1973).

Mathematically, a profit-maximizing regulated firm attempts to maximize the following function:

$$\Pi = R(K,L,E) - wL - fE - cK \tag{2.4.1}$$

subject to:

$$\frac{R(K,L,E) - wL - fE}{K} = s \ ,$$

where:

Π = Profits

$R(\ )$ = Total revenue

K = Capital (in value units)

L = Labor

E = Units of emissions

w = Wage rate

f = Emissions charge

c = Competitive cost of capital

s = Allowable rate of return. 1/

Forming the Lagrangian, we obtain

$$L = R(K,L,E) - wL - fE - cK + \lambda\left[\frac{R(K,L,E) - wL - fE}{K} - s\right], \tag{2.4.2}$$

1/ It is assumed here that the allowable rate of return, s , exceeds the cost of capital ($s > c$) and that the constraint binds so that it can be written as an equality. If this were not the case, the firm would simply behave as an unconstrained profit-maximizing monopolist.

where λ represents the Lagrange multiplier. Taking the required partial derivatives, setting them equal to zero, and solving for the firm's optimal use of inputs generates the following three conditions:

$$R_K = c + \frac{\lambda}{1+\lambda}(s - c) \tag{2.4.3}$$

$$R_L = w \tag{2.4.4}$$

$$R_E = f , \tag{2.4.5}$$

where R_i is the marginal revenue product of factor i.

At first glance, one might inter from Equations (2.4.3) through (2.4.5) that the firm is indeed a cost-minimizer with respect to pollution abatement. However, this is incorrect. [1] Cost minimization, from society's perspective, occurs only if the ratios of the marginal products to factor prices (where the latter reflect true social opportunity costs) are identical for all factors. This is obviously not the case since:

$$\frac{R_K}{c + \frac{\lambda}{1+\lambda}(s - c)} = \frac{R_L}{w} = \frac{R_E}{f} \tag{2.4.6}$$

Note that if the regulatory constraint were not binding, λ would equal zero and the profit-maximizing solution would imply cost minimization since R_K would equal c . As it stands, however, the firm faces an implied cost of capital that is below the market price; hence, the firm employs excess capital in production.

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[1] Baumol and Klevorick (1970) stress this point; see pp. 176-7.

As a hypothetical example, one might envision a regulated firm that employs excess capital in the form of pollution-abatement equipment. Again, the expanded capital stock would permit a higher absolute level of profits. However, for the same reasons outlined above, the implied marginal cost of abatement would exceed the emissions charge, since the firm would substitute capital for emissions to an extent that is unjustified by the true opportunity costs of the factors. Under these circumstances, a system of emissions charges could not be expected to generate the least-cost set of pollution-abatement quotas among polluters.

Somewhat curiously, one cannot even conclude that an increase in an emissions charge will induce a reduction in pollution emissions from a regulated firm. As proof of this, one can site Bailey's finding that for the two-factor case, a rise in the wage rate need not lead to reduced labor input. 1/ This ambiguity is strengthened in the model presented above due to the inclusion of emissions as an input with the corresponding increase in factor-substitution possibilities.

If instead of maximizing profits, the regulated firm seeks to maximize revenues, the outcome involves a similar, but opposite, distortion: underutilization of capital. 2/ To see this we alter the previous model. The revenue-maximizing regulated firm attempts to maximize the following function:

1/ See Bailey (1973), pp. 135-7.

2/ See Baumol and Klevorick (1970), pp. 180-2; and Bailey (1973), pp. 81-4.

(2.4.7) $R = R(K, L, E)$

subject to:

$$\frac{R(K, L, E) - wL - fE}{K} = s$$

where the notation is as before. Forming the Lagrangian:

(2.4.8) $$L = R(K, L, E) + \lambda \left[\frac{R(K, L, E) - wL - fE}{K}\right] - s$$

and taking the required partial derivatives and setting them equal to zero yields the following first-order conditions:

(2.4.9) $$\frac{R_K}{s} = \frac{R_L}{w} = \frac{R_E}{f}$$

In this case, instead of equalizing marginal revenue products of the factors to their prices (as is required for efficiency in production), the revenue-maximizing regulated firm "underutilizes" capital. This follows, since, by assumption, $s > c$ (that is, the allowable rate of return exceeds the competititve cost of capital).

The intuitive rationale for this result is that, by reducing its capital inputs, the firm lessens the absolute level of profits it must generate to meet its rate-of-return constraint. This, in turn, allows greater scope for increasing revenue by effectively easing the contraint. Unfortunately, this also introduces further ambiguity into predicting the behavior of the regulated firm under an economic incentive scheme. While, the prescribed allowable rate of return will, in general, create an incentive for the firm to adopt other than the cost-minimizing combination of factor inputs, without additional information on the firm's objective function, one cannot even predict the direction of this distortion.

Whether a profit maximizer or a revenue maximizer, the regulated firm will have an incentive to employ other than the cost-minimizing combination of factor inputs. Moreover, it is seldom possible to determine whether the regulated firm will exhibit tendencies toward suboptimal or excessive levels of output.

Thus, the cost-minimization theorem under the standards-and-charges approach cannot readily be extended to include regulated firms. The implementation of a system of emissions charges could, in principle, lead either to a net improvement or to a net deterioration in allocative efficiency. One cannot predict unambiguously what the impact of the charge will be on factor proportions; with three factors this would depend upon the elasticities of substitution between the factors. Similarly, one cannot reach unambiguous conclusions concerning the effect of a charge system on the regulated firm's level of output (although there is a presumption that the higher cost of an input will typically result in reduced output).

While this conclusion is admittedly disturbing, there remains the important practical question concerning the actual magnitude of the distortions. Baumol and Klevorick venture that the A-J effect of over-capitalization is not likely to produce serious distortions. They base this on the fact that firms are unlikely to have the extensive information or the refined decision processes that would be necessary to lead unerringly to significant A-J input distortions.[1] Thus, in terms of policy evaluation, the complications introduced by rate-of-return regulatory constraints may be second-order effects.[2] If so, this would mean that such effects would not be too damaging to the case for market incentives to control pollution.

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[1] See Baumol and Klevorick (1970), pp. 188-9.

[2] Oates and Strassmann (1978) were unable to find compelling evidence of a widespread A-J effect among regulated firms.

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CHAPTER 4

METHODS OF QUANTITATIVE ANALYSIS

4.1 Introduction

This chapter describes the methods of analysis that we have employed to determine the consequences of alternative choices of policy instruments to control NO_x emissions. In spite of the fact that we shall be delving into some fairly involved mathematics whose main purpose is to lay the foundation for later analyses, this is an important chapter in its own right and should be (at least) skimmed thoroughly by all readers. It explains, for example, the conceptual relationship between our simulation model in Chapter 5 and our analyses of policy designs in Chapters 6 and 7. It also presents an analysis of the performance of alternative policies under uncertainty that is the foundation for many conclusions we have drawn. So bear with us, please.

In undertaking our analyses, we have attempted to answer two questions. The first question is, what effect does the choice of control policies have on ambient concentrations of NO_2? In examining this question, we have taken as a basic ground rule that an acceptable plan for controlling NO_x emissions must be effective in meeting and maintaining ambient standards for NO_2. It should be pointed out, however, that no control plan -- whether it is based on regulations or economic incentives -- provides absolute assurance that standards will be attained and maintained. Rather, plans differ in the likelihood that they will attain and maintain standards. Thus, where possible, in our analyses we consider the effects of alternative policies on the likelihood of attainment and maintenance of ambient standards for NO_2.

The second question we address is, what effect does the choice of policies have on the costs of controlling NO_x? In answering this question, we have attempted to examine all of the costs associated with alternative control plans including costs incurred by polluters to administer their programs and to monitor their emissions, costs incurred by the public sector to administer, monitor, and enforce programs, and costs associated with any market distortions that are introduced. Often there are trade-offs between these different components of the total costs of control. For example, it will be seen in subsequent chapters that some policies are relatively cheap to administer, monitor, and enforce, but such policies may require relatively large expenditures of resources for technically controlling emissions. In general, the analyses that follow are intended to estimate the order of magnitude of these trade-offs so that the choice between alternative policies can be based upon a comparison of the full costs of each.

It will be useful in this and subsequent chapters to distinguish between "policies" and "strategies". By "strategies" we mean simply a set of emissions limitations applied to sources. We will use strategies as calculational devices to explore the consequences of alternative policy designs. By "policy" we mean the institutional apparatus by which a pollution control authority implements a strategy. We discussed two broad types of policy in Chapter 3. These were regulation and economic incentives.

The cost and effectiveness of a policy depends upon the cost of making and administering it, and, the cost and effectiveness of the strategy it induces. If a policy induces an efficient (i.e., low cost) and effective (i.e., meets environmental standards) strategy, and is relatively simple to make and administer, then, other things being equal, this policy is likely to be a cost-effective one.

We argued in Chapter 3, on largely qualitative grounds, that a policy based on economic incentives is likely to be superior to one based on regulation in both of these dimensions of cost. In particular, we showed that procedural requirements make regulatory policy both costly and cumbersome to administer. We also showed that there is a presumption that properly designed economic incentives policies will induce the adoption of efficient and effective emission control strategies, and that regulatory policies in general will not.

The results of our analyses in Chapter 3 are purely qualitative. They do not tell us whether the cost and effectiveness advantages of economic incentives policies are large or small. To determine this requires a quantitative analysis of alternative policies. This is the task on which we embark in this chapter and continue in the remaining chapters of the report.

We noted above that there are two factors to consider in estimating the cost and effectiveness of a policy alternative:

- cost of making and administering policy
- cost and effectiveness of strategies resulting from policy.

The methods we shall describe in this chapter are designed to estimate the latter type of cost and effectiveness. Our methods for estimating the costs of making and administering policies are described in Chapters 6 and 7.

The plan of this chapter is as follows. In Section 4.2, the basic model we have used for our analysis of cost and effectiveness of alternative emission control strategies is described. This model -- called a "mathematical programming model" in the literature -- allows one to determine the levels of emissions controls that are needed on the sources in an air quality control region in order to achieve a given ambient standard at least cost. It can also be used to simulate the cost and effectiveness of a wide variety of other "non-least-cost" strategies.

Section 4.2 also shows the connection between least cost strategies and economic incentive policies. In particular, we show how the results of a mathematical programming analysis can be used to calculate the emissions charge rates that would just induce sources to adopt the emission controls required to implement the least cost strategy, or the permit prices that would result from competition for marketable emissions permits.

In Section 4.3 we consider the possibility that mathematical programming analyses could be used to improve the performance of regulation. Our treatment in this section is a more rigorous development of the treatment of this topic contained in Section 3.5 of Chapter 3. This analysis compares regulation based upon mathematical programming to marketable permits and to emissions charges on the basis of two criteria. These criteria are expected (in a rigorous mathematical sense) costs and the dispersion (as measured by the variance) of the distribution of resulting ambient concentrations about the mean ambient concentration. Our analysis will show that, under certain reasonable assumptions about the degree of knowledge possessed by different actors in air pollution control, economic approaches clearly have lower expected costs than does regulation even if the latter is based upon a mathematical programming analysis. Our analysis also will show that the two economic approaches we consider both lead to the same expected cost, and that a marketable permit policy and regulation result in less uncertainty about the ambient concentrations than does an emissions charge policy.

4.2 An Illustrative Mathematical Programming Model

The starting point of our analysis of plans for the control of stationary-source NO_x emissions is an examination of alternative emission control strategies and their effects on the control expenditures necessary to achieve an ambient NO_2 standard. Other things being equal, it is desirable that these control outlays be as small as possible. If this were not the case, then there would be unnecessary waste in the utilization of resources to meet the ambient air quality objective. To aid us in our initial analysis, we have employed a mathematical technique called "mathematical programming." This procedure allows us to identify specific control strategies that will meet ambient air quality constraints at lowest total control costs.

4.2.1 The Basics of Mathematical Programming

The fundamental idea behind mathematical programming is quite simple. We will describe this technique in the context of a sample decision problem. Specifically, the problem will be one of setting emissions limitations for a number of pollution sources in a hypothetical air quality control region such that control costs are as low as possible and the total emissions from all sources will not violate an ambient air quality standard.

In the mathematical programming representation of the problem, there are three basic elements. These are as follows: [1]

- Variables -- denoted by $E_1, E_2, \ldots, E_{N_s}$. In our example, these are the emissions to be achieved by each of the N_s sources.
- Constraints -- denoted by $E_i \geq 0$, $i = 1, \ldots, N_s$ and $\sum_{i=1}^{N_s} d_{ij}E_i \leq S$, $j = 1, \ldots, N_r$. In our example, the first type of constraint indicates that it is impossible to attain emissions levels of less than zero and the second constraint indicates that the emissions levels must be sufficiently low to insure that the ambient air quality standard is met at each of N_r receptors.
- Objective function -- denoted by $C(E_1, E_2, \ldots, E_{N_s})$. In our example, this function represents the costs of controlling emissions at all N_s sources. It can be thought of as a "scoring function" that indicates how "good" or how "bad" is the decision concerning the levels at which emissions are set.

Given these three basic elements, our example problem can be stated as follows: find the emissions levels $E_i \geq 0$, $i = 1, \ldots, N_s$ that (if attained) will meet the ambient air quality constraint, S, at all N_r receptors and at the same time will do so at least total control costs.

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[1] Complete definitions of the notation are given below.

Once the problem is set up in this way, mathematical programming techniques provide insight into the qualitative nature of the solutions. We shall make use of both of these aspects in our analysis.

4.2.2 Qualitative Properties of the Solutions

Under rather restrictive assumptions concerning the nature of the individual pollution source's control cost functions, we can derive certain properties of the solution to the problem of achieving an ambient air quality standard at least cost.[1] For this purpose, we adopt the following notation:

$E_i \geq 0$ = Emissions of the i^{th} source, constrained to be non-negative.

$C_i(E_i) \geq 0$ = Cost of emissions control for the i^{th} source, constrained to be non-negative.

$C_i'(E_i) \leq 0$ = Derivative of the cost function $C_i(\cdot)$ with respect to emissions, E_i; that is, the marginal cost of emissions control is assumed to be decreasing with increasing emissions. We also assume that $C_i''(E_i) \geq 0$.

d_{ij} = Contribution of the i^{th} source emissions to concentrations at the j^{th} receptor, per unit of emission.

$S \geq 0$ = Ambient standard, constrained to be non-negative.

N_s = Number of sources.

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[1] These assumptions are stronger than those imposed in our actual computations of least-cost control strategies.

N_r = Number of receptors.

$\lambda_j \leq 0$ = Lagrange multiplier, constrained to be non-positive.

Using this notation, we may reformulate the problem as follows:

(4.2.1)[1]
$$\underset{E_i}{\text{minimize:}} \sum_{i=1}^{N_s} C_i(E_i)$$
$$\text{subject to:} \sum_{i=1}^{N_s} d_{ij}E_i \leq S \qquad j = 1, \ldots, N_r$$

This, in turn, can be written as minimizing the following Lagrangian:

(4.2.2)
$$L = \sum_{i=1}^{N_s} C_i(E_i) + \sum_{j=1}^{N_r} \lambda_j \sum_{i=1}^{N_s} [S - d_{ij}E_i]$$

The corresponding Kuhn-Tucker necessary conditions for solutions to this problem are:

(4.2.3a)
$$C_i'(E_i) - \sum_{j=1}^{N_r} \lambda_j d_{ij} \geq 0 \qquad i = 1, \ldots, N_s$$

(4.2.3b)
$$\left[C_i'(E_i) - \sum_{j=1}^{N_r} \lambda_j d_{ij}\right] E_i = 0 \qquad i = 1, \ldots, N_s$$

(4.2.3c)
$$S - \sum_{i=1}^{N_s} d_{ij}E_i \geq 0 \qquad j = 1, \ldots, N_r$$

(4.2.3d)
$$\lambda_j \left[S - \sum_{i=1}^{N_s} d_{ij}E_i\right] = 0 \qquad j = 1, \ldots, N_r$$

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[1] In this chapter only, all equations are numbered according to the principal section in which they fall (e.g., 4.2.1 instead of 4.2.2.1).

Focusing for the remainder of this discussion on "interior" solutions to the problem (that is, solutions in which all emissions, E_i, are strictly greater than zero), one may deduce from Equation (4.2.3a) that the optimal solutions will have the following property:

$$(4.2.4) \qquad C_i'(E_i) = \sum_{j=1}^{N_r} \lambda_j d_{ij} \qquad i = 1, \ldots, N_s$$

The interpretation of Equation (4.2.4) is that, in order to minimize control costs subject to the ambient air quality constraint, emissions levels for each source must be such that the reduction in control costs from an increase in emissions at the margin, $C_i'(E_i)$, is just equal to a weighted sum of the diffusion coefficients that relate the source's emissions to ambient concentrations at the various receptors.

The weights on the right-hand-side of Equation (4.2.4) are what we have defined above as Lagrange multipliers. These multipliers have an important interpretation in terms of the relationship between the level at which the ambient air quality constraint is set and the level of total control costs necessary to meet that constraint. In particular, it can be shown that:

$$(4.2.5) \qquad \lambda_j = \partial C / \partial S_j$$

Equation (4.2.5) states that the j^{th} Lagrange multiplier represents the marginal change in total control costs that would result from a marginal change in the level of the ambient air quality constraint. This marginal value is frequently termed the "shadow price of the j^{th} resource" in other applications of mathematical programming.

4.2.3 Programming Models and Optimal Incentives

To see why this interpretation of the Lagrange multipliers is useful, suppose that one were to contemplate increasing the i^{th} source's emissions by one unit above the level implied by the "optimal" emissions limitation (that is, above the level specified in the solution to the mathematical programming model). This would result in an increase in ambient concentrations at the k^{th} receptor of d_{ik}. To maintain the ambient standard, this, in turn, would require that other sources reduce their emissions by an amount sufficient to decrease concentrations at the k^{th} receptor by d_{ik}. These reductions in emissions limitations are not costless. In particular, the impact on the total costs of control would be approximately equal to $-\lambda_k d_{ik}$, the shadow price of concentrations at the k^{th} receptor multiplied by the decrease in contributions to ambient concentrations from other sources necessary to maintain the ambient standard. Hence, the value (i.e., increased cost) to society, at the margin, of one unit of emissions from the i^{th} source is:

$$(4.2.6) \qquad t_i = -\sum_{j=1}^{N_r} \lambda_j d_{ij}$$

Equation (4.2.6) represents the amount that total control costs would change if the i^{th} source's emissions changed incrementally about the optimum. Thus, the variable t_i may be regarded as the shadow price (that is, the implied value to society) of a unit change in the i^{th} source's emissions.

Recall from Chapter 3 that the basic idea behind economic policy approaches to air pollution control is to insure that emitters take into account the costs that their emissions impose upon others. Economic approaches do this by insuring that emitters pay a price for their emissions. Under emissions charge plans, this price is simply the charge rate or rates that apply to emissions; under marketable emissions permit plans, this price is the permit price. The crucial feature of the price is that it must reflect the incremental cost to society of additional quantities of emissions.

The analysis which leads to Equation (4.2.6) above tells us exactly at what levels prices on emissions must be set in order to reflect this cost. In particular, under a charge system designed to implement a least cost emission control strategy, the charge rate on the i^{th} source's emissions would be set at the shadow price on those emissions, or t_i. Under a marketable permit program, the system must be organized in such a fashion that the price of permits reflects the marginal value of emissions found in Equation (4.2.6) if the permit system is to lead to a least cost strategy. Accordingly, in our considerations of detailed designs of economic policy approaches in Chapters 6 and 7, we will make use of marginal values like those shown in this equation.

4.2.4 Programming Models and Economic Growth

The basic expository model set out above (and the actual model we have used) does not deal explicitly with growth and change. Each of the basic parameters and equations of our programming model in fact changes over time. For example, the number of sources may tend to grow or to shrink, the size of sources may tend to change, cost relationships may change over time with changes in factor prices and changes in technology, and so forth.

In principle, each of the time-changing features could be incorporated into our model by putting dates on each variable and parameter, adding any constraints on intertemporal relationships among variables, and treating each variable at each date as a separate variable. Instead of formulating our objective as minimization of annual cost subject to ambient constraints, we would minimize the present value of costs over some specified time horizon. The solution which results would give us a sequence of strategies (i.e., a sequence of values for emissions for each source) that would minimize the present value of costs subject to attainment and maintenance of ambient standards.

In practice, accounting for time-changing features is difficult. It increases the number of variables and parameters in the basic static model by a factor of approximately T, where T is the number of time periods to be considered, and it generally increases the number of constraints in the model. It also makes it more difficult (but not impossible) to derive qualitative results which characterize the results of optimal solutions, and to see the intuitive connection between these solutions and optimal incentive structures. For these reasons we have chosen not to include time-changing factors explicitly in our expository model.

4.3 Uncertainty, Programming Models, and the Evaluation of Policies

In Section 4.2.3 above, we described how the solution of a mathematical programming model could be used to calculate the charge rates that would be required to attain ambient standards efficiently, or to simulate the effective prices per unit of emissions that would result from the operation of a marketable permit system. While these are the main uses we shall make of programming model solutions in subsequent chapters of this report, it should be pointed out that programming models like those described above could, in principle, also be used as a tool for improving the efficiency of direct regulation. In this application, programming models would be used by control agencies to find the set of emissions regulations that would attain ambient standards at least cost. These regulations would then, presumably, be promulgated.

This latter possibility certainly has intuitive appeal. It retains the basic institutional structure that has been erected to cope with environmental pollution, and it seems to promise the same benefits of effectiveness and economic efficiency that are promised by charges and marketable permits.

It must be remembered, however, that mathematical programming models, like all models, are only as good as the data which go into them. In order to formulate and solve the programming models described in the preceding section, several different kinds of information are needed, including information on emissions, emissions characteristics (e.g., height, temperature), on control technology cost and effectiveness, opportunities for invention and innovation of new control technologies, sources' (existing or potential) expansion plans, and diffusion relationships. If erroneous values for these parameters are used in their construction, erroneous results are likely to be obtained from their solution. This is true whether we use mathematical programming models to find cost-effective (if the model is correct) regulations or to calculate incentive rates for an economic incentives policy.

The consequences of erroneous models and the results in these two different uses (setting of regulations versus setting of incentives) are very different, however. Regulations set on the basis of an erroneous model will result in inefficiency, in the sense that resources expended for ambient air quality achieved will be greater than necessary. Incentive rates based on an erroneous model of economic policies will lead to erroneous conclusions about the magnitude of potential costs and ambient improvements associated with different policies. However, if sources know and follow their own best economic interest, we can still be assured that economic policies will result in efficient abatement in the sense that resources expended for the amount of abatement obtained will be minimal.

This is an important point, for as we saw in Chapter 2 and will see again in Chapter 5, the data currently available to control agencies on stationary source control of NO_x are almost certainly erroneous, and perhaps seriously so. For example, it is highly improbable that control agencies could obtain by any direct means accurate information on sources' costs of control. Each source is sui generis, and small differences in sources may make large differences in control cost relationships. This, in turn, could result in large (and costly, as we shall illustrate below) errors in the setting of emissions limitations. These difficulties are only compounded when we consider the possibilities of technical change and expansion or contraction of sources.

Clearly, different decision-makers possess different degrees of knowledge about the basic cost and diffusion parameters. Those having to do with specifics of individual source's operations (emissions, emissions characteristics, cost and effectiveness of control technology, opportunities for invention and innovation of new control technology, and expansion plans) are best-known to sources. [1] Those having to do with diffusion relationships probably are best-known to control agencies.

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[1] It has been suggested to us that small sources (e.g., space heating) may not have accurate knowledge of these specifics. Strictly speaking, this may be true. However, the private sector infrastructure that sells and services the small sources' equipment should possess this knowledge, and be able to apply it when emissions controls are called for.

The practical strength of incentive-based approaches to pollution control is that they tend to divide the responsibility for decision-making along roughly the same lines that detailed knowledge about the various parameters relevant to cost-effective control is divided. Under regulation, the control agency decides (within the limits of procedural fairness) almost everything. Under a charges approach, the agency sets and revises charge levels and individual sources select their levels of emissions in light thereof. Under a permits approach, the agency selects the number of permits to issue and sources, bargaining with one another in the marketplace for permits, determine how permits will be allocated and what prices they shall bear.

Ideally, the considerations of accuracy and cost of information about the basic parameters of air pollution control would be incorporated directly into our mathematical programming analysis. This could be done, for example, by performing a large number of simulations under different assumptions about true and perceived parameter values. Unfortunately, resource constraints prevented us from following this course. We can nonetheless return to the analysis in Chapter 3 (see Section 3.5.1) to compare policy approaches analytically. As will be recalled, our analysis in Chapter 3 concluded that economic approaches have lower expected costs than does enlightened regulation. We also argued that a marketable permit approach would result in as much certainty about the level of ambient concentrations as would a regulatory approach, although an emissions charge approach would result in less certainty.

4.3.1 Notation and Preliminaries

We can demonstrate these conclusions by means of a relatively simple analysis which parallels a similar analysis of economic planning due to Weitzman (1974). For this purpose, it is helpful to introduce a modest amount of notation, and some simplifying assumptions. Our basic assumptions are these:

(a) We confine our attention to the case of a single receptor.

(b) Let $C_i(e_i, u_i)$ represent the i^{th} source's cost function, where e_i represents its quantity of emissions, and u_i is a random variable representing the control agency's uncertainty about the source's costs.

(c) Let $d_i(v_i)$ represent the uncertain coefficient of proportion relating units of emissions from the i^{th} source to ambient concentrations at a receptor. "v_i" is a random variable representing the agency's uncertainty about the diffusion relationship.

(d) Let s represent an ambient standard.

(e) $E(v_i, u_j) = E(v_i)E(u_j) = 0$, where E is the mathematical expectation operator; that is, the random variables u_i and v_j are statistically independent for all i and j.

(f) In view of uncertainty in the diffusion relationship, the agency seeks control policies that achieve expected ambient concentrations equal to the ambient standard.

(g) The source knows its control costs with certainty.

These assumptions are stronger than strictly required to be able to derive the results obtained below. In particular, we do not need to assume (as we do in (g) above) that sources are certain about their costs; it is sufficient to assume that they are less uncertain than the agency is. We also speculate that we could replace assumption (f) with the weaker assumption that the agency attempts to control the probability that the ambient standard is exceeded. This latter assumption corresponds well with the current definition of standards, which set limits on the frequency of ambient concentrations in excess of the standard level.

4.3.2 Specification of Alternative Policies

Our objective, recall, is to compare three different policy approaches. Under the first approach, which represents what we have called "enlightened regulation" above, the agency minimizes expected costs subject to achieving expected ambient concentrations equal to the ambient standard. We may formulate this problem mathematically using the notation set forth above as

$$(4.3.1) \qquad E\left\{\sum_{i=1}^{N_s} C_i(\hat{e}_i, u_i)\right\} = \underset{e_i}{\text{minimum}} \; E\left\{\sum_{i=1}^{N_s} C_i(e_i, u_i)\right\}$$

$$\text{subject to} \quad E\left\{\sum_{i=1}^{N_s} d_i(v_i)e_i\right\} = s$$

The solutions $\hat{e}_i$ are the emissions regulations which minimize expected costs subject to the ambient constraint, and

$$E\left\{\sum_{i=1}^{N_s} C_i(\hat{e}_i, u_i)\right\}$$

is the expected cost under this set of regulations.

The second policy approach we examine requires the agency to set emissions charges so as to minimize expected cost while attaining expected ambient concentrations equal to the ambient standard. Let $h_i(p_i, u_i)$ be the function which relates the i^{th} source's emissions to the charge level set. The random variable u_i is included reflecting the fact that the agency, since it does not know the source's cost function, cannot be certain about the source's response to any given emissions charge. Then using the notation established above, the agency's problem is to find the $\tilde{p}_i$ such that

$$(4.3.2) \qquad E\left\{\sum_{i=1}^{N_s} C_i(h_i(\tilde{p}_i, u_i), u_i)\right\} = \underset{p_i}{\text{minimum}} \; E\left\{\sum_{i=1}^{N_s} C_i(h_i(p_i, u_i), u_i)\right\}$$

$$\text{subject to } E\left\{\sum_{i=1}^{N_s} d_i(v_i) h_i(p_i, u_i)\right\} = s$$

The third policy approach we examine requires the sources to bid to purchase permits from the agency. The agency is to sell no more permits to sources than would result in expected ambient concentrations just equal to the ambient standard. We will assume that each source bids the maximum amount it is willing to pay for permits. Each submits its bids in the form of a demand schedule for permits.

The marginal cost savings to, say, the first source from purchase of an incremental permit is simply $-C_1'(e_1, u_1)$. This then is the amount that it would be willing to pay for the last permit unit purchased, and represents the first source's demand function for permits. Assuming that the agency does not wish to charge a monopoly price for permits, but rather to maximize the net value of (i.e., willingness to pay for) permits issued subject to the constraint that ambient standards be met on an expected value basis, it can be shown that the agency's problem is to choose the number of permits to issue to each source, $\bar{e}_i$, such that

$$E\left\{\sum_{i=1}^{N_s} C_i(0, u_i) - C(\bar{e}_i, u_i)\right\} = \underset{e_i}{\text{maximum}}\; E\left\{\sum_{i=1}^{N_s} C_i(0, u_i) - C(e_i, u_i)\right\} \tag{4.3.3}$$

$$\text{subject to } E\left\{\sum d_i(v_i)e_i\right\} = s$$

which is precisely equivalent apart from the constant terms $E\left\{C(0, u_i)\right\}$ to

$$E\left\{\sum_{i=1}^{N_s} C_i(\bar{e}_i, u_i)\right\} = \underset{e_i}{\text{minimum}}\; E\left\{\sum_{i=1}^{N_s} C_i(e_i, u_i)\right\} \tag{4.3.4}$$

$$\text{subject to } E\left\{\sum d_i(v_i)e_i\right\} = s$$

where $E\{\sum C(\overline{e}_i, u_i)\}$ represents expected total costs at the optimal permit allocation.

The most important thing to note about equation (4.3.4) is its similarity to equation (4.3.1). There is, however, one important difference. Equation (4.3.4) represents the problem faced by the agency *before* it has received bid schedules from the sources. In fact, the problem that the agency will solve begins *after* it has received bid schedules. This means that, under our assumption that firms are perfectly certain about their costs and base their bids upon them, the agency will be perfectly certain about control costs at the time it makes its permit allocation. This means that it can set an allocation that *exactly* minimizes costs.

4.3.3 Analysis of Alternative Policies

Our problem in this analysis is to compare the results of each of the policy approaches described above in terms of two criteria. The first criterion is the expected cost to which each approach leads. Other things being equal, we should prefer a policy approach which leads to lower expected cost to one which leads to higher expected cost. The second criterion is the variance of expected ambient concentrations. We have constrained all policies to result in expected ambient concentrations equal to the ambient standard. This being the case, other things being equal, we would prefer policies that result in a relatively tight distribution of ambient concentrations around the ambient standard.

Accordingly, in the analysis to follow, each step is taken to produce manageable expressions for expected costs and for the variances of ambient concentrations. These expressions are then compared to deduce the extent to which one policy is better than another in terms of the criteria we have adopted.

The starting point for our analysis is a quadratic approximation of the sources' cost functions. This is done because it is far easier to work with quadratic forms than general functional forms, and because in many instances quadratic forms provide quite good approximations. We will approximate the cost functions about the point $\hat{e}_i$ by the functions

$$C_i(e_i, u_i) \doteq a_i(u_i) + (C_i' + \alpha_i(u_i)(e_i - \hat{e}_i)) \quad \frac{1}{2} C_i''(e_i - \hat{e}_i)^2 \tag{4.3.5}$$

where the $a_i(u_i)$, and $\alpha_i(u_i)$ are random variables, and where the C_i' and C_i'' are constants. The sign $\doteq$ means "approximately equal".

We shall assume that the $\alpha_i(u_i)$ have been standardized so that $E\{\alpha_i(u_i)\} = 0$ for all i. Note also that since u_i and v_i are independent for all i and j by assumption, $E\{\alpha_i(u_i)d_i(v_i)\} = E\{\alpha_i(u_i)\} \cdot E\{d_i(v_i)\} = 0$.

The basic approximations given in equation (4.3.5) and assumptions about the random errors imply several other approximations that will be useful in the analysis we shall develop below. The most important of these are the following:

$$\frac{dC_i}{d e_i} = C_i'(e_i, u_i) \doteq (C_i' + \alpha_i(u_i)) + C_i''(e_i - \hat{e}_i) \tag{4.3.6}$$

$$E\{C_i'(\hat{e}_i, u_i)\} \doteq C_i' \tag{4.3.7}$$

$$E\{C_i''(e_i, u_i)\} = C'' \tag{4.3.8}$$

Note that equations (4.3.7) and (4.3.8) provide us with an interpretation of each of the fixed coefficients which appear in our basic approximating equation (4.3.5).

We now have all of the basic ingredients and relationships required to explore the relative expected costs and certainty of attainment of ambient standards. There is a fair amount of manipulation and substitution and analysis involved in deriving the results we will obtain, so perhaps it will be useful here to comment on the analytical strategy we are pursuing as we follow through the steps.

We will begin by comparing optimal regulation [as described in equation (4.3.1) above] to optimal charges [as described in equation (4.3.2) above]. Our first step in this comparison will be to derive an explicit approximate expression for the functions $h_i(p_i, u_i)$, which gives the distributions of emissions levels (as perceived by the emissions-charge-setting agency) which would result from any given set of charges, p_i. Which levels of emissions actually arise depends, of course, on the value taken by the u_i, which is known under our assumptions only by the sources.

The second step of our analysis is to substitute the expressions we derive for $h_i(p_i, u_i)$ into the equations representing the problem of finding a price to minimize expected cost [equation (4.3.2) above], and to find an expression for the values of the p_i, which we have denoted as $\tilde{p}_i$, which solve this problem.

The third step is to take the resulting expression for $\tilde{p}_i$, substitute it in our approximate expression for costs [i.e., equation (4.3.5) above], and evaluate expected costs. This yields an estimate of expected costs which we will compare with a similar expression for expected costs evaluated at $\hat{e}_i$. This comparison will show that the expected total cost of the optimal emissions charge policy is lower than the expected total cost of the optimal regulation policy.

The final step in our comparison of optimal regulation and optimal charges is to compare the variances of the resulting distributions of ambient air quality. Our analysis will show that optimal regulation has a smaller variance in ambient concentrations than does optimal charges, with the size of the difference in the variances related to the same factors which tend to give an optimal charge policy an expected cost advantage. That is, the larger the expected cost advantage that an optimal charges policy has over optimal regulation, the greater the dispersion of the distribution of ambient concentrations about the standard level.

Our comparison of an optimal marketable permit policy with optimal regulation and optimal charges follows a similar sequence of steps to that outlined above. Our analysis will show, as noted above, that the expected costs of a marketable permit policy under our assumptions are precisely equivalent to those of an optimal charges policy, and hence are less than those of optimal regulation. We will also show that the dispersion of the distribution of ambient concentrations resulting from a marketable permit policy is the same as that of optimal regulation, and less than that resulting from an optimal charges policy.

Proceeding according to the strategy outlined above, we begin by deriving an approximate expression for the functions $h_i(.)$ which relate sources' resulting emissions levels to charge levels. We know that for the i^{th} source to minimize costs when faced with an emissions charge p_i and state of nature u_i, it will adjust emissions to the point where

$$-C_i'(e_i, u_i) = -C_i'(h_i(p_i, u_i), u_i) = p_i \tag{4.3.9}$$

That is, it will adjust emissions to the point where its incremental cost saving from increasing emissions is just equal to its incremental charge liability from increasing emissions.

Substituting our approximate expression for the derivative of the cost function in equation (4.3.9), we obtain

$$- (C_i' + \alpha_i(u_i)) - C''(h_i(p_i, u_i) - \hat{e}_i) \doteq p_i$$

which after rearrangement yields the following approximate expression for the functions $h_i(.)$.

$$\tilde{e}_i(u_i) = h_i(p_i, u_i) \doteq \hat{e}_i - \frac{p_i + C_i' + \alpha_i(u_i)}{C_i''} \quad i=1, \ldots, N_s \tag{4.3.10}$$

These functions give the cost minimizing level of emissions that will be chosen by each source at any charge level. The random term $\alpha_i(u_i)$ which appears in each equation reflects the fact that the agency does not know with certainty what level of emissions each source will pick because it does not know each source's costs with certainty.

The next step we shall take to find the set of charges that minimizes expected costs is to substitute equation (4.3.10) into our approximating expression for costs, and to evaluate approximate expected total costs. When this is done, we obtain

$$E\left\{\sum_{i=1}^{N_s} C_i(h_i(p_i, u_i), u_i)\right\} \doteq E\left\{\sum_{i=1}^{N_s} \left[a_i(u_i) + \left(C_i' + \alpha_i(u_i)\right)\left(-\frac{p_i + C_i' + \alpha_i(u_i)}{C_i''}\right) + \frac{C_i''}{2}\left(\frac{p_i + C_i' + \alpha_i(u_i)}{C_i''}\right)^2\right]\right\} \tag{4.3.11}$$

$$= \sum_{i=1}^{N_s} \left[E\left\{C_i(\hat{e}_i, u_i)\right\} + \frac{1}{2}\,\frac{p_i^2 - C_i'^2}{C_i''} - \frac{1}{2}\,\frac{\sigma_i^2}{C_i''}\right]$$

where $\sigma_i^2 = E\left\{\alpha_i(u_i)\,\alpha_i(u_i)\right\}$.

Using the approximate expression for expected total costs given in equation (4.3.11) above, we proceed to find an expression for the set of prices which minimize this expression and attain expected ambient concentrations approximately equal to the standard. This is done by minimizing (4.3.11) with respect to the p_i, subject to the expected air quality constraint. The first order necessary conditions for this are

$$\tilde{p}_i = \lambda \check{d}_i \qquad i=1, \ldots, N_s$$

$$\sum_{i=1}^{N_s} \check{d}_i\, E\left\{\hat{e}_i - \frac{\tilde{p}_i + C_i' + \alpha_i(u_i)}{C_i''}\right\} = s \tag{4.3.12}$$

where $\check{d}_i = E\left\{d_i(v_i)\right\}$. Note that since we require expected ambient concentrations under optimal regulation to be equal to the standard level, the constraint equation presented in (4.3.12) implies that $\tilde{p}_i = -C_i'$. This, in turn, implies (by substituting back in equation (4.3.1.0)) that at the optimal charge rates, the distribution of emissions rates perceived by the agency is

$$\tilde{e}_i = \hat{e}_i - \alpha_i(u_i) \qquad i=1, \ldots, N_s \tag{4.3.13}$$

and that expected costs under the optimal charge policy as given by equation (4.3.12) evaluated at $p_i = -C_i'$ are

$$\sum_{i=1}^{N_s} \left[E\left\{ C_i(\hat{e}_i, u_i) \right\} - \frac{1}{2} \frac{\sigma_i^2}{C_i''} \right] \tag{4.3.14}$$

4.3.4 Results and Conclusions

Inspection of equation (4.3.14) reveals immediately that the expected costs of the optimal charges policy are less than the expected costs that would result from the optimal regulation policy. This can be seen by noting that the expected costs of the optimal charges policy are equal to the expected cost of the optimal regulation policy less a term which depends upon the variances of the intercepts of the marginal cost functions. The difference between the expected cost of an optimal regulation policy and the expected cost of an optimal charge policy is

$$\Delta \doteq \frac{1}{2} \sum_{i=1}^{N_s} \frac{\sigma_i^2}{C_i''} \tag{4.3.15}$$

The expected cost advantage of the optimal charge policy comes at a price, however. The variance of ambient concentrations under the optimal regulatory policy is simply

$$(4.3.16) \qquad V_e = \sum_{i=1}^{N_s} \check{\check{d}}_i \hat{e}_i^2$$

where $\check{\check{d}}_i$ is the variance of $d_i(v_i)$. In contrast, the variance of ambient concentrations under the optimal charges policy can be shown (by substituting the expression for the e_i contained in equation (4.3.10) into the constraint equation and evaluating the variance of the resulting expression) to be

$$(4.3.17) \qquad V_i = \sum_{i=1}^{N_s} \check{\check{d}}_i \hat{e}_i^2 + \check{\check{d}}_i \frac{\sigma_i^2}{C_i''}$$

This is clearly larger than the variance of ambient concentrations under optimal regulation, and the difference between the two increases with increasing uncertainty about sources' costs.

Our comparison of optimal regulation to optimal charges thus leads us to the conclusion that an optimal charges policy leads to lower expected cost, and less certainty about resulting ambient concentration, than does a policy of optimal regulation. The more uncertain are sources' cost functions, the larger the cost advantage of an optimal charges policy relative to an optimal regulatory policy, and the greater the ambient air quality certainty advantage of an optimal regulatory policy over an optimal charges policy. Any choice between these policies thus rests upon weighing the benefits of cost savings against the benefits of greater certainty concerning ambient air quality. Since we have no information on the benefits of ambient air quality, we have no basis for making this comparison here. We simply point out that this trade-off has to be made in order to decide which of the two policies -- optimal regulation or optimal emissions charges -- is better.

It is a relatively simple matter to extend the analysis presented above to consideration of the expected cost and dispersion of ambient concentrations which would result from an optimal marketable permit policy. Under this type of policy, given our assumptions that sources always know exactly their cost functions and reveal them in bidding for permits, the agency allocates an amount of permits to each source, $\bar{e}_i$, such that 1/

$$C_i'(\bar{e}_i, u_i) = \lambda \check{d}_i \tag{4.3.18}$$

Setting our approximate expression for incremental costs in equation (4.3.6) above equal to the right-hand side of equation (4.3.18) above and solving for $\bar{e}_i$, we obtain

$$\bar{e}_i \doteq \hat{e}_i - \frac{\lambda \check{d}_i + C_i' + \alpha_i(u_i)}{C_i''} \tag{4.3.19}$$

1/ Equation (4.3.18) follows directly from the first order necessary conditions for the problem stated in equation (4.3.4) above.

Note the striking similarity between equations (4.3.19) and (4.3.10). Indeed, they are precisely the same equation, and a full analysis of the first order conditions leading to equations (4.3.18) and (4.3.19) above paralleling our analysis in equation (4.3.12) above leads to the conclusion that the optimal allocation $\bar{e}_i$ of permits under the optimal marketable permit system is

$$(4.3.20) \qquad \bar{e}_i = \hat{e}_i - \alpha_i(u_i)$$

It follows immediately, by substitution back into our approximate expression for costs and taking expectations, that the optimum marketable permit system enjoys the same expected cost advantage that is enjoyed by the optimum emissions charge system. That is, expected costs under the optimum permit system are less than expected costs under optimum regulation by the amount given in equation (4.3.15) above.

In computing the variance of the distribution of ambient concentrations resulting from an optimum marketable permit system we proceed as we did above for the emissions charge policy, with one very important exception. Under the marketable permit plan, the agency learns the $\alpha_i(u_i)$ from sources through the bids submitted prior to making its decisions. The $\alpha_i(u_i)$ are thus no longer random variables at the time the decision is made, and the variance of ambient concentrations is given approximately by equation (4.3.16) -- the equation which gives the variance of ambient concentrations under the optimum regulation policy.

This is a most interesting result. If we accept the assumptions upon which it rests, we conclude that both a marketable permit and an emissions charge policy have a cost advantage over a regulatory policy. We also conclude that the variance of ambient concentrations under a marketable permit policy is equal to that under a regulatory one. Based on our two criteria, expected cost and the precision with which a policy attains ambient standard levels, our analysis thus leads to the conclusion that a marketable permits policy is the best policy approach.

We must hasten to add that this result is based upon a particular theoretical model and some definite assumptions. While the model and assumptions seem reasonable enough, we do not know how sensitive our conclusions are to changes in them. In subsequent chapters in which we present more detailed investigations of alternative policies we will deal with these same issues again on a more pragmatic, less theoretical, basis. Interestingly, our conclusions are the same. In particular, we find practical reasons -- all basically related to the fact that different parties at interest in air pollution control each possess different information -- which we believe favor a marketable permit approach.

REFERENCES TO CHAPTER 4

Weitzman, M. "Prices vs. Quantities," Review of Economic Studies 4, 1974, pp. 477-491.

CHAPTER 5

MATHEMATICAL PROGRAMMING ANALYSIS OF ALTERNATIVE EMISSION CONTROL STRATEGIES

5.1 Introduction

In this chapter we present the results of a mathematical programming analysis like that described in Chapter 4 (see Chapter 4, Section 4.2). These results will form a basis for comparing the costs of alternative policy designs to implement NO_x control.

The calculations we make in this chapter will focus on comparisons of the results of strategies that do not equate abatement costs at the margin to the results of strategies that do. We associate the former type of strategy with current regulatory policy and the latter type with the economic alternatives we have examined in previous chapters and will examine further in subsequent chapters. No attempt is made, due to time and data limitations, to simulate the effects of uncertainty, or the results of a strategy that might result from what we have termed "enlightened regulation" in Chapters 3 and 4. To do this would require Monte Carlo simulations, which were beyond our means for this project. We do, nonetheless, have the qualitative results presented in Chapters 3 and 4, which tell us that policies based upon economic incentives probably would dominate in comparisons based on such simulations. Moreover, results we will present below will indicate that model solutions are quite sensitive to assumptions, which is an indication that were we to conduct simulation comparisons of enlightened regulation to economic policies, we would probably find the latter to dominate by a good margin.

Our results presented in this chapter will show that strategies designed to achieve air quality standards by distributing the burden of emissions control in a fashion that recognizes the differential costs of control as between sources and the differential impact of sources on ambient air quality can result in substantial savings. In particular, we estimate that in Chicago, the most efficient program of controls possible (source-by-source controls) for meeting a short-term NO_2 standard of 250 $\mu g/m^3$ would entail expenditures for emissions control (expressed on an annualized basis) of approximately \$21 million, evaluated in 1978 prices. This compares with estimated control expenditures needed to meet ambient standards under current regulatory programs of between \$94 million and \$254 million, depending upon the sophistication with which emissions control regulations are established.

These results certainly are consistent with those presented in previous studies of the scope for economizing on control expenditures. They add further support to the conclusion that it may be possible to save large amounts of money by fashioning control programs that take advantage of opportunities to economize.

The plan of the chapter is as follows. In Section 5.2 we describe the mathematical programming model we have used to analyze emission control strategies. We also describe the input data on emissions diffusion and ambient concentrations that are used in the model. 1/

As will be explained in Section 5.2, our air quality analysis is based upon a 1976 inventory of stationary point sources of NO_x emissions,

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1/ The cost data inputs are described in Chapter 2, Section 2.4.

with no adjustment for growth in these sources. While some adjustment has been made to current levels of area source emissions (reflecting primarily our projections to the effect of control of NO_x emissions from automobiles -- which we treat as area sources in our analysis), our source inventory roughly reflects current conditions. Accordingly, our estimates of ambient concentrations and costs strictly pertain only to the control of existing sources.

Section 5.3 reports the results of our optimization analysis of five basic emissions control strategies for meeting a short-term standard of 250 $\mu g/m^3$ in Chicago (along with some variations on selected strategies). These strategies will provide the basis for calculations of cost and effectiveness of alternative economic incentive systems in subsequent chapters. They also will provide a basis for comparing the cost and effectiveness of policies that encourage economization with those which do not. The five basic strategies analyzed are as follows:

- No Control Baseline - which applies no control relative to a one-hour averaging standard for stationary source emissions of NO_x.
- Reasonably Available Control Technology (RACT) - which applies demonstrated emissions control technologies that are economically affordable. [1]
- Least Cost Control - which applies that set of emissions controls which is estimated to achieve

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[1] Since there is currently no short-term standard for NO_2, RACT as yet has no official definition for any source category in any region.

ambient standards at least annualized cost. It is this set of controls which economic incentive policies are intended to achieve.

- Selective Emission Controls - which applies a uniform level of emission controls to all sources in those categories of sources in which one or more sources are controlled in the least cost strategy. This strategy represents what might be achieved under current regulatory policy, or under an incentives policy with certain limitations on design.
- Rollback - which requires all plants to achieve the same percentage reduction in emissions, with this uniform percentage emissions reduction being sufficient to achieve ambient standards. This strategy represents what might be achieved under the crudent application of today's regulatory policy.

Section 5.4 briefly considers the cost of alternative strategies to attain an ambient standard of 500 $\mu g/m^3$ over a one-hour averaging time. Our analysis shows that the costs of meeting this standard are quite low (on the order of \$1 million or less). We conclude that if a short-term standard were set at 500 $\mu g/m^3$ or above, the wisest policy for implementing the standard probably would be to continue current regulatory policy, which probably would be relatively efficient and effective in ferreting out the few "problem sources" requiring control.

Section 5.5 presents our conclusions. As noted above, our main conclusion is that the pure least cost strategy requires significantly lower control cost expenditures than do the other control strategies. However, as we shall see in the following chapters, the implementation of this strategy raises some difficult practical problems. The cost differentials should thus be viewed simply as indicative of the savings that could be realized IF (and this is appropriately a big "if") certain barriers to economizing approaches can be surmounted.

5.2 An Overview of the EEA Mathematical Programming Model [1]

The mathematical programming model discussed in the preceding section describes the basic concepts of mathematical programming models and the conclusions that can be drawn from them. To facilitate our discussion, we made a number of simplifying assumptions. For example, we assumed that control cost could be expressed as a smooth (i.e., differentiable) function of emissions. In fact, the data we have on control costs (see Chapter 2, Section 2.4.3) imply that costs are not a smooth function of emissions, but rather are a step-function.

In order to accommodate this and other features of realistic air pollution control strategies, we have utilized a special kind of a mathematical programming model called an integer programming model. Like the illustrative model described in the preceding chapter, the integer programming model described in this section finds the least cost strategy for attaining ambient standards. It differs only in that it imposes different assumptions on the analysis, which better characterize available data.

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[1] The EEA Programming Model was developed by Energy and Environmental Analysis, Inc., 111 North 19th Street, Arlington, Virginia, 22209.

5.2.1 An Overview of the Model [1]

Before laying out some of the details of the EEA model, it is useful to discuss in general terms the inputs and outputs of the model. These are shown schematically in Figure 5.2.1.1 below. As this figure shows, there are five inputs into the model, including:

- estimates of the contribution of each source to concentrations at each receptor
- control cost data
- total NO_2 concentrations at each receptor
- the short-term ambient standard to be met
- the control strategy to be followed.

The model which processes these inputs operates in two modes. First, it can be used to find the least cost emissions control strategy. It does this by solving a mathematical programming problem (which is described in more detail in Appendix A to this chapter). Second, it can be used to simulate any arbitrary (i.e., non-least cost) strategy.

For each strategy analyzed, the model produces two kinds of estimates. First, it estimates the annual cost of emissions control associated with each strategy. This provides a basis for comparing

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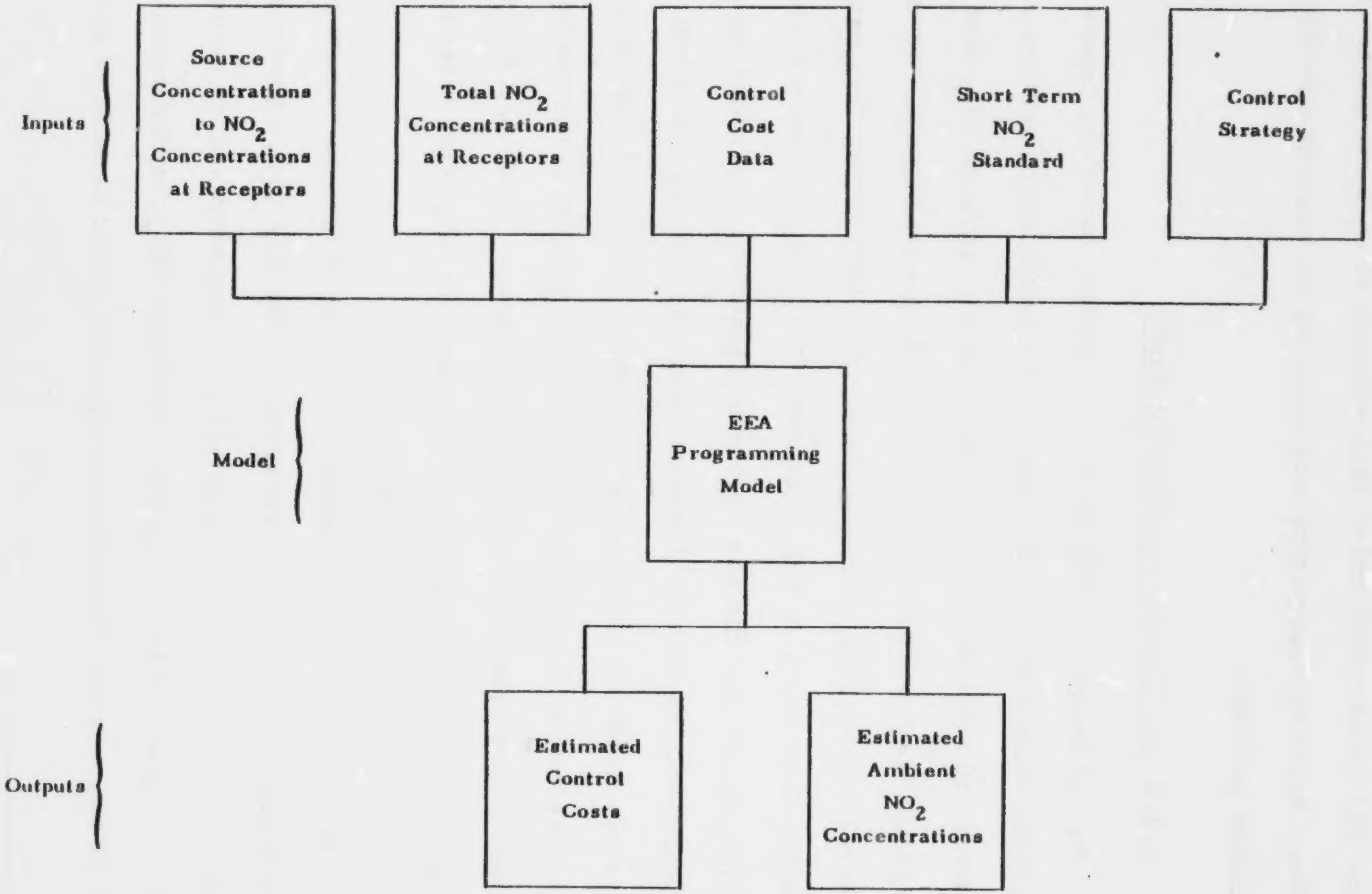
[1] A mathematical description of the EEA model is presented in Appendix A to this chapter.

Figure 5.2.1.1

A Schematic of the EEA Model


Inputs
Source Concentrations to NO2 Concentrations at Receptors
Total NO2 Concentrations at Receptors
Control Cost Data
Short Term NO2 Standard
Control Strategy
Model
EEA Programming Model
Outputs
Estimated Control Costs
Estimated Ambient NO2 Concentrations

strategies on the basis of cost. Second, it estimates the ambient concentrations that would result under each strategy at each receptor. This provides a basis for comparing strategies on the basis of effectiveness in reducing pollution.

5.2.2 Air Quality Assessment Model

As can be seen in Figure 5.2.1.1 above, two of the inputs required to apply the EEA model involve data on the relationship between source emissions and ambient impact. Unfortunately, ambient NO_2 data for the Chicago Air Quality Control Region (AQCR) are inadequate, taken alone, for characterizing and assessing the short-term ambient NO_2 problem. Currently there are only four continuous NO_2-NO_x monitors in the Chicago AQCR, far below the number needed to adequately cover an area approximately 150 km. by 80 km. Nevertheless, the four sites are representative of severely impacted locations in the region. The peak one-hour NO_2 levels observed at these sites are among the highest concentrations observed in any urban area of the United States. Table 5.2.2.1 shows the highest and second highest yearly one-hour NO_2 level measured at these sites during the past three years.

In order to evaluate further the extent of the short-term NO_2 problem in the Chicago AQCR, it was necessary to develop an air quality assessment model. For this purpose, a multiple point and area source model known as RAM, was used for assessing the short-term NO_x concentrations. [1] RAM is an EPA-approved, Gaussian steady-state model capable of predicting

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[1] See Novak and Turner (1976).

Table 5.2.2.1

Highest and Second Highest Yearly One-Hour NO_2 Levels ($\mu g/m^3$)

Monitoring Site	1975		1976		1977	
	Highest 1-hr. NO_2	Second Highest 1-hr. NO_2	Highest 1-hr. NO_2	Second Highest 1-hr. NO_2	Highest 1-hr. NO_2	Second Highest 1-hr. NO_2
Camp	394	385	490	470	na	na
Medical Center	678	616	394	338	1008[a]	968[a]
Joliet	857[a]	812[a]	262	250	494	442
Lasalle	na	na	na	na	604	524

a/ Questionable data.

na - not available.

Source: Illinois Environmental Protection Agency short-term (averaging times ranging from an hour to a day) ambient concentrations of relatively stable pollutants from multiple point and area sources. The model requires hourly meteorological data on wind direction, wind speed, stability class, and mixing height. In addition, the data required on the point sources consist of source coordinates, emissions rate, physical stack height, stack gas volume flow, and stack gas temperature. Area sources are specified in terms of the south-west corner coordinates of the area source grid, the total grid cell area, the total cell emissions rate, and the effective area source height.

As noted, RAM is designed for modeling nonreactive pollutants. However, nitrogen dioxide (NO_2) is primarily a secondary pollutant formed by oxidation of nitric oxide (NO). The initial NO concentration in the exhaust gases, the plume diffusion and travel time, and the ambient concentration of photochemical oxidants and reactive hydrocarbons are all important factors that affect the conversion of NO in a plume to NO_2. Therefore, a dynamic model of NO_2 formation from point source emissions of NO_x was developed by EEA and used in conjunction with RAM to predict the NO_x concentrations at a receptor due to point sources and to translate them into NO_2 concentrations. 1/

With regard to area sources, a fixed NO_2/NO_x ratio for each period of the day based on the observed data at the continuous monitoring sites was used to translate ambient NO_x concentrations into the corresponding NO_2 levels. 2/

1/ A discussion of this model is presented in Appendix B to this chapter.

2/ This subject is discussed further under the section on assumptions and limitations, Section 5.2.7, p. 5-19.

5.2.3 Point and Area Source Emissions Data

A partial listing of point-source emissions information together with stack parameter data were obtained from Radian Corporation.[1] Additional information on NO_x sources including such pertinent data as source operating rate, and certain classification codes were obtained from EPA's NEDS point-source subfile and from the Illinois EPA.

The hourly NO_x emissions data obtained from Radian were adjusted to reflect the diurnal and seasonal variation in operating loads.[2] Emissions factors for most utility boilers and combustion turbines were based on actual stack test data. For other point sources, the most up-to-date emissions factors available were used.[3] In addition, the point source data were screened for erroneous and missing information. Default values for various parameters were substituted when necessary. Such values were based on what constituted a normal operating practice for the particular process category being considered. The total data set consisted of 1621 point sources belonging to approximately 286 plants. However, for the final analysis, point sources emitting below 10 pounds of NO_x per hour were considered too small to be treated separately; hence, they were combined with the area-source inventory. This was done primarily to reduce the number of point sources serving as the input to RAM. The final number of plants and sources used for the air quality assessment model were 233 and 797, respectively.

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[1] See Eppright et al. (1978).

[2] The temporal variations in the operating loads of power plants and space heating operations were found to be more significant than those associated with industrial operations.

[3] The sources for the emissions factors included: Aerotherm (1977), California Air Resources Board (1974), and EPA (1976).

Hourly NO_x emissions estimates for the mobile- and stationary-area sources in the Chicago region were also provided by Radian Corporation. 1/ The basic source of vehicular data was the Chicago Area Transportation Study (CATS) which was used to convert the 1975 annual average mobile-source emissions (taken from NEDS) into hourly emissions during the summer and winter seasons. The mid-morning and afternoon hourly area-source emissions were apportioned to 5 km. × 5 km. grid cells. Input data to the area-source subroutine of RAM consisted of 640 cells. 2/

5.2.4 Meteorological Data

Meteorological conditions play a major role in the short-term build up of pollutants from both point and area sources. High ground level concentrations from point sources are normally caused by fumigation (inversion breakup) or plume downwash where the plume intersects the ground quickly. The meteorological parameters that characterize these conditions are a stability class of B or C (unstable atmosphere) and moderate to high wind speeds. High ground level

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1/ See Eppright *et al*. (1978).

2/ A finer spatial resolution for the area-source emissions would have resulted in prohibitive computer costs.

impacts from vehicles and other area sources occur when the atmosphere is quite stable (stability class D or E), wind speeds are low, and mixing heights are small. Thus, the meteorological conditions that maximize the impact of point sources are at the opposite extreme from those that maximize the impact of ground level area sources; hence, it is difficult to estimate their simultaneous maximum impact. To circumvent this problem, several sets of meteorological conditions were used to simulate worst-case conditions for point and area sources together.

The actual meteorological data for the Chicago AQCR used in the analysis were extrapolated from the mixing height and wind speed data collected by the National Weather Service at their Greenbay, Peoria, Flint, and Dayton stations. 1/ Typical meteorological conditions as well as those that correspond to stagnant and unstable atmospheres in the Chicago AQCR are shown in Table 5.2.4.1.

5.2.5 Receptor Locations

A total of 370 receptors were selected initially to cover the Chicago AQCR. They were located so that the maximum impact of all significant point and area sources could be captured. The first 70 receptors corresponded to locations of the continuous and 24-hour NO_2 monitoring sites in the Chicago AQCR. The remaining receptors

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1/ See Holzworth (1972, 1974, 1978).

Table 5.2.4.1

Meteorological Conditions Used in the Air Quality Assessment Model

Conditions	Season and Hour of the Day		
	Summer Mid-Morning	Summer Afternoon	Winter Mid-Morning
Typical			
• Wind Speed	4.0 meters/sec.	6.5 meters/sec.	6.0 meters/sec.
• Mixing Height	650 meters	1600 meters	450 meters
• Stability Class	C	D	D
• Wind Direction	90°	225°	315°
• Ambient Temperature	70°F.	80°F.	20°F.
Worst Case - Point Source Impact			
• Wind Speed	2.5 meters/sec.	4.5 meters/sec.	2.50 meters/sec.
• Mixing Height	300 meters	800 meters	300 meters
• Stability Class	C	B	C
• Ambient Temperature	70°F.	80°F.	20°F.
Worst Case - Area Source Impact			
• Wind Speed	0.5 meters/sec.	2.5 meters/sec.	1.5 meters/sec.
• Mixing Height	300 meters	800 meters	200 meters
• Stability Class	C	D	D
• Ambient Temperature	70°F.	80°F.	20°F.
Predominant Wind Directions	90°	180° 225°	270° 315°

Source: Holzworth (1972, 1974, 1978).

were selected by RAM downward of significant point and area sources at locations of expected maximum impact.

Specifically, RAM proceeds by selecting the 100 most significant point sources and the 100 most significant area sources based on their relative contribution to ambient concentrations. Two receptors downwind of each major point source are then selected. The first receptor for both the point and the area sources is located at the estimated point of maximum ambient impact, and the second receptor, applicable only to point sources, is in the same direction but twice as far from the point source. The purpose of the second receptor is to capture the interaction of overlapping plumes.

The 100 receptors corresponding to the major area sources were eliminated after the preliminary modeling runs because total NO_2 concentrations at these receptors were considered insignificant. Thus, for the final analysis 270 receptors remained. The model was then run for five predominant wind directions in the Chicago AQCR to capture the interaction between various sources. Then, for each significant point source, the downwind receptors with the highest concentrations were selected for the purpose of developing control strategies.

5.2.6 Results

Several preliminary runs of the model were made to determine the combinations of hourly emissions and meteorological conditions that would result in the highest short-term NO_2 concentrations. [1/]

[1/] These runs were made using data from a portion of the Chicago AQCR that included Cook, Dupage, and sections of Will, Lake, and Porter counties.

High hourly NO_2 values were estimated at several receptors for both sets of "worst case" conditions depicted in Table 5.2.4.1. However, these conditions are distinct in that they select for point source impacts on the one hand and area source impacts on the other, with limited interaction between these source types under either set. To test for the possibility that the highest hourly NO_2 levels could result from area and point source interaction, an intermediate set of meteorological conditions was specified:

- Wind Speed - 1.5 meters per second;
- Stability Class - C; and
- Mixing Height - 300 meters.

The NO_x emissions used with these conditions correspond to the 1975 summer mid-morning levels. Since these conditions indeed led to the highest estimated ambient NO_2 levels (see Table 5.2.6.1), they were used in the final analysis.

The results indicated the presence of two distinct types of point sources: (1) large plants with tall stacks such as power plants, and (2) plants with a large number of smaller sources with short stacks such as steel mills and refineries. The diffusion characteristics of emissions from the second category were found to be similar to those of the area-source emissions. During meteorological conditions that caused high concentrations from both the point sources with short stacks and the area sources, point sources such as power plants caused low concentrations due to their high effective stack heights. This is illustrated by the results presented in Table 5.2.6.1, which compares the relative point- and area-

Table 5.2.6.1

Comparison of Point and Area Source Contributions Under Different Meteorological Conditions a/

	Meteorological Conditions								
	Worst Case - Point Source			Worst Case - Area Source			Intermediate Case		
	Total	Point	Area	Total	Point	Area	Total	Point	Area
Number of Receptors above 200 $\mu g/m^3$ b/		47			68			67	
Average for all Receptors above 200 $\mu g/m^3$ b/	277	165	111	341	142	199	316	142	174
Five Highest Receptors:									
1	509	428	81	568	549	19	603	493	110
2	589	409	81	479	279	200	602	434	168
3	348	209	139	472	272	200	600	407	193
4	348	225	123	472	272	200	598	430	168
5	342	219	123	472	272	200	553	383	170
Percentage of Power Plants with Significant Contributions c/		17%			0%			3%	

a/ Study area includes Cook, Dupage, and sections of Will, Lake, and Porter counties.

b/ The 200 $\mu g/m^3$ level of concentration is for a one-hour averaging period.

c/ Defined as effective stack height less than mixing height.

source contributions to ambient NO_2 concentrations under three different meteorological conditions. It should be noted that while some extreme meteotological conditions could result in point sources with tall stacks having greater individual impacts, these same conditions tend to minimize the impact of other source category emissions with the result being that overall concentrations are relatively low. Thus, the point sources with short, multiple stacks and the area sources seem to be the dominant cause of high short-term NO_2 concentrations in Chicago. 1/

Since the objective of this study was to evaluate alternative approaches for the control of point sources of NO_x, special control strategies for area sources were not tested. However, area-source emissions were reduced by 20 percent to account for the expected reduction in the NO_x emissions from mobile sources by 1982. This 20 percent reduction, applied uniformly to all grid cells, is a first-order approximation. It is based on the following assumptions:

- the percentage of mobile-source NO_x emissions to all morning area-source NO_x emissions in every cell is 75 percent;
- by 1982 mobile-source emissions will be reduced by 25 percent; and
- vehicle miles traveled (VMT) are assumed to grow at an annual rate of one percent.

1/ This is in agreement with the conclusions of EEA's preliminary assessment of the short-term NO_2 problem. See EEA (1978a).

5.2.7 Limitations

Previous work by EEA on characterizing the NO_2 problem from both point and area sources was valuable in developing this relatively sophisticated approach for estimating short-term NO_2 concentrations.[1] Nevertheless, there remain important limitations in the analysis that are associated with the underlying assumptions. These assumptions includ the following:

1. The meteorological conditions are assumed to hold for a period of one hour and are assumed to be uniform over the whole AQCR. Uniformity is not likely to be very realistic because of the variations in the topography across the region. In addition, center city meteorological conditions are considerably altered by the "built" environment. However, a "microscale" analysis seemed unwarranted in view of the objectives of this study and the prohibitive resources that it would have required. Thus, the NO_2 concentrations may have been underestimated due to these factors.
2. Mobile-source emissions are uniformly distributed throughout each grid cell. This results in a loss of spacial resolution that may reduce the impact

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[1] See, especially, EEA (1978b).

of these emissions on air quality. The uniformity assumption is again questionable since ambient levels of the mobile-source pollutants (HC, CO, NO_x) tend to peak near roadways and normally diffuse within relatively short distances. Thus, NO_2 levels, though considerably smoothed due to the slow conversion rate of NO to NO_2, are still significantly higher in the vicinity of roadways. To circumvent this problem, some version of a highway model would be needed to estimate the impact of mobile sources more accurately.

3. As noted above, the NO_x concentrations due to the point sources were transformed to NO_2 concentrations by use of a dynamic plume-specific approach incorporated into RAM. (See Appendix B to this chapter.) However, the translation of NO_x emissions from area sources to NO_2 concentrations was accomplished by using a fixed NO_2/NO_x factor of 0.5. This factor was derived from hourly NO_2 and NO_x data for the summer morning period recorded at the continuous monitoring stations in the Chicago AQCR. In general, the daily NO_2/NO_x ratios for the mid-morning period ranged from 0.4 to 0.6. Nevertheless, it is probable that on some days, the monitors were influenced by area sources

to a greater degree than on others. Furthermore, the factor of 0.5 was applied to all area sources. While it is true that NO_x emissions from area sources are mixed with the atmosphere homogeneously within relatively short distances of the point of discharge, concentrations in the immediate vicinity of discharge point may differ. Notwithstanding, it seemed reasonable to assume that for a given period of the day, the ratio of NO_2 to NO_x concentrations across area sources would be similar.[1/] This assumption should be considered only as a crude approximation.

5.3 Mathematical Programming Analysis

The objective of the mathematical programming analysis was to provide a basis for comparing the relative efficiency of alternative policy designs (measured in terms of total control costs) to attain short-term NO_2 standards. Two short-term standards were analyzed: 250 $\mu g/m^3$ and 500 $\mu g/m^3$ (for a one-hour averaging period). The results of our analysis of alternative strategies will be used in Chapters 6 and 7 to compute certain parameters of alternative policy designs and to compare the costs of these alternatives.

[1/] The narrow range of NO_2/NO_x ratios observed at the continuous monitoring stations support this assumption.

5.3.1 Alternative Control Strategies

The cost of achieving a specific ambient standard is a function of both the level of the standard and the emissions limitations adopted by sources that are believed to contribute to violations of the standard. As was discussed above, a sophisticated interactive point and area source model was employed to determine source-receptor relationships. The purpose of the model was to estimate the degree to which specific point sources must control in order to achieve a given ambient standard.

Since the choice of which sources should be controlled (and at what level they should be controlled) depends critically upon the strategy selected, five distinguishable control approaches representing the range of what might be achieved by alternative policy designs were examined. They ranged from the No Control Baseline in which no point source instituted emissions controls to a Simple Rollback in which every major source was required to install emissions controls. The five strategies are discussed, in turn, below.

5.3.1.1 No Control Baseline

The purpose of analyzing this strategy was to establish the degree to which the Chicago AQCR might be experiencing a significant attainment problem for any given short-term NO_2 standard and the degree to which stationary sources would contribute to the problem. To analyze this case, the model was run assuming that the 1975 emissions characteristics pertained to each point source in the Chicago AQCR. 1/ These emissions

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1/ Area-source emissions were averaged over 5 km. x 5 km. grid cells.

characteristics presumably account for point-source controls, if any, that were required to ensure attainment of an annual NO_2 standard, but they do not include any provisions relating to the attainment of a short-term NO_2 standard. A total of 1621 point sources were included in the inventory. [1]

As indicated in Section 5.2.5, 270 receptor locations remained for the simulation study. Of these, 104 indicated potential violations of a 250 $\mu g/m^3$ one-hour standard under the No Control Baseline. In considering this, it is important to recognize that a single source can contribute to high concentrations at several receptors. Therefore, if that source is controlled, it will have an impact not only on the receptor at which the source is having its maximum impact, but also on other receptors at which the source contributes a measurable concentration of NO_2.

The incremental costs of control for the No Control Baseline option were assumed to be zero. This assumption is equivalent to postulating that a short-term standard is not set. In that case, point sources would continue to contribute directly to high short-term NO_2 levels despite the fact that they might be in compliance with an annual NO_2 ambient standard.

5.3.1.2 Reasonably Available Control Technology (RACT)

This regulatory strategy assumes that all point sources implement controls that have been demonstrated and that are "economically affordable," as would be defined by Illinois and EPA's regional office. [2] RACT strategy ignores the contribution of any specific source to high short-term concentrations. Therefore, it requires sources that contribute to violations to control to the same extent as sources that do not contribute to violations. Further, there is no assurance that this strategy will achieve the standard at all receptors.[1]

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[1] It is essential to note that "point source" here is equivalent to a source classification code (SCC) source. Thus, several "point sources" may be found in one plant.

[2] The definitions used for purposes of this study are thus hypothetical approximations of what eventually may be defined as RACT. See the Chapter 2, Section 2.3.1, for a discussion of the role of RACT in current regulatory policy.

5.3.1.3 Least Cost

The Least Cost strategy was found by using the EEA Programming Model described in Appendix A to this chapter. Briefly, the solution is determined by solving the model such that the ambient standard is met at all receptors while at the same time emissions control costs are minimized. This strategy is intended to approximate what would be achieved under an "ideal" economic incentive policy.

In order to implement this type of approach, the environmental authority would find it necessary to model every significant (as defined by the procedures discussed in Section 5.2.3 above) point source as well as a large number of receptors for every set of meteorological conditions likely to cause high short-term NO_2 levels. From this modeling, it would then select the set of maximum source-receptor relationships corresponding to each point source. For each receptor, each source would then be controlled up to the level at which its incremental cost of control per unit of reduction in ambient concentration ceased to be less than that for any other source contributing to that receptor. Once the source with the lowest marginal cost is controlled to this level, other sources are controlled in sequence starting with the source with the next lowest marginal cost until the standard is achieved.

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[1] Indeed, as the results below will demonstrate, a RACT strategy would not achieve a 250 $\mu g/m^3$ short-term NO_2 standard at every receptor.

As a variation on the Least Cost strategy, we examined what would happen if RACT were adopted by all sources and then costs were minimized subject to this constraint. This case was an attempt to consider the effect of existing provisions of the law together with whatever additional controls were necessary to meet a short-term ambient standard at the receptor locations. Specifically, the installation of RACT was first assumed. Then additional emissions controls were applied in a cost-minimizing manner. [1/] The difference in costs of control between this case and the Least Cost strategy was the incremental cost of RACT over and above those controls necessary to ensure attainment of a short-term standard.

5.3.1.4 Selective Emissions Controls

This strategy requires the application of a uniform set of emissions level controls across all sources in a particular source category. Specifically, for the Chicago AQCR, nine source classifications were designated based on EPA's Source Classification because the control cost functions used in the model were keyed to individual SCC's. Thus, the emissions control level specified for a particular source category was determined to be the highest control level required for an emitter in that class to attain ambient standards, as determined by examining the results of the Least Cost strategy discussed above.

[1/] New sources would have been required to purchase offsets and install LAER controls; however, these costs were not considered here.

The Selective Emissions Control strategy roughly reflects the kind of strategy that might be expected to result from a relatively sophisticated use of today's implementation planning methods. It thus represents what might be thought of as the regulatory baseline strategy.

5.3.1.5 Simple Rollback

In general, this strategy has been used in the past to meet annual or other long-term air quality standards. Where ambient concentrations show little variation throughout a region, a case can be made that rollback is a reasonable approximation to the degree of emissions control required. However, such situations are not common; hence, rollback generally results in significant overcontrol. This is especially true in situations dealing with a short-term standard since violations usually involve high concentrations associated with a single or only a few point sources impacting a particular receptor. Nevertheless, in order to establish an upper bound for the total control costs that might be incurred in meeting the short-term NO_2 standard at receptors in the Chicago AQCR, a simple rollback analysis was performed. Under this approach, all sources were required to reduce emissions by a fixed percentage. The degree of reduction was determined by the formula:

$$\text{Percent Reduction} = \frac{R_h - S}{R_h - B} \times 100 \qquad (5.3.1.5.1)$$

where: R_h = Highest concentration recorded at any receptor in the region.

S = Ambient NO_2 standard.

B = Background NO_2 levels associated with sources not controlled.

For example, if the standard were 250 $\mu g/m^3$, the background level were 50 $\mu g/m^3$, and the highest reading at any receptor were 500 $\mu g/m^3$, the required degree of rollback would be 56 percent [(500 - 250)/(500 - 50)] × 100.

Requiring rollback for the entire Chicago AQCR should result in the highest possible degree of control necessary to achieve the ambient standard as well as the highest control costs. To make this approach more reasonable economically, the needed percentage reductions were specified for entire plants rather than for individual sources.[1] Thus, a Least Cost strategy could be applied to all sources within a given plant.

5.3.2 Discussion of Chicago Results

The five control strategies discussed above were evaluated using the EEA Programming Model. One additional test was made that simulated maximum feasible controls on all emissions sources (Maximum Feasible Control).[2]

Table 5.3.2.1 presents the basic results. The table shows the number of sources that were required to control emissions under each option, the pounds of emissions reduced under each option, the number of receptors that continued to be in violation after controls were installed, and the annualized costs associated with each control strategy.

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[1] This is analogous to current practice under EPA's "Bubble" policy.

[2] Maximum feasible control for a source category is assumed to be the highest level of control shown in the corresponding control technology and cost tables in Chapter 2. See Chapter 2, Section 2.4.

Table 5.3.2.1

Optimization Analysis Results for Chicago

(1978 dollars)

	Number of Sources Controlled	Pounds of NO_x Emissions Reduced (10^3 lb/hr)	Number of Receptors in Violation (250 $\mu g/m^3$)	Annual Control Costs (10^6 $/yr)
No Control Baseline	0	0	104	0
RACT	797	37	80	23
Least Cost	96	5	0	21
RACT with Least Cost	797	40	0	44
Selective Emissions Control	742	29	0	94
Simple Rollback				
90 percent	797	106	0	254
80 percent	792	104	6	243
Maximum Feasible Control	797	106	0	254

5.3.3 No Control Baseline

As noted above, under this option no change in emissions controls are assumed to occur for purposes of achieving a short-term NO_2 standard. The model run was based on the 1975 emissions characteristics for the point sources in the Chicago AQCR. As can be seen, of the 270 receptor locations used in the final analysis, 104 indicated potential violations of a 250 $\mu g/m^3$ NO^2 standard. Since we have assumed that no emissions controls will be applied in the absence of a short-term standard, incremental control costs are assumed to be zero.

5.3.4 RACT

Under the RACT strategy, all sources implement some form of emissions control. The degree of control implemented is based on currently demonstrated control technology. [1] In general, all sources implement Level 2 controls unless only the first level was feasible for retrofitting existing sources. [2] Implementation of RACT resulted in a net reduction of 37,000 pounds of NO_x hourly emissions (at maximum capacity). This would be equivalent to approximately 25 percent of the maximum feasible emissions reduction. Under RACT, 80 receptors remain in violation of the 250 $\mu g/m^3$ standard. The costs associated with implementing RACT are estimated to be $23 million per year.

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[1] See Chapter 2, Section 2.4 on Control Technologies and Costs, page 2-14.

[2] "Level 2 controls" are those given in the second row of the cost tables shown in Chapter 2.

5.3.5 Least Cost

Under the Least Cost strategy only 96 sources must be controlled in order to bring all receptors into compliance with the 250 $\mu g/m^3$ NO_2 standard. Thus, only approximately 12 percent of the total population of polluters need to apply any emission control whatsoever. The net reduction in NO_x emissions is only 5000 pounds per hour; however, this is sufficient to attain the ambient standard at all receptor locations. The associated annual costs with the Least Cost approach are $21 million.

The RACT with least cost variation, as previously stated, is an attempt to simulate a hybrid of the current regulatory policy and an economically efficient approach. First, all sources are required to control using RACT. Then only those sources that remain in violation of the short-term NO_2 standard are required to implement additional controls. As can be seen in Table 5.3.2.1, this case brings all receptors into compliance at an annual cost of $44 million. The incremental level of emissions controlled over the RACT case alone is 3,000 pounds of NO_x per hour. By comparing this case with the Least Cost option, it can be seen that while attainment is assured in both cases, the incremental costs associated with requiring RACT are $23 million, or the full amount of RACT alone. The explanation of this is that the control costs associated with implementing RACT at sources violating the short-term standard are very small (less than $1 million annually). Thus, the $21 million in control costs associated with the Least Cost option are primarily due to emissions controls over and above RACT. While RACT alone does bring 24 receptors into compliance, the costs of achieving the same results with a Least Cost approach would be substantially less. Nevertheless, RACT with least cost may be somewhat easier to implement than the Least Cost strategy alone since it might allow a greater growth increment for certain locations in the region. However, because our optimization analysis did not attempt to deal explicitly with future growth considerations, the benefits of a RACT baseline cannot be evaluated adequately.

5.3.6 Selective Emissions Control

This strategy represented an attempt to circumvent the need for the source-by-source emissions limitations that would be required to implement the Least Cost option. As described earlier, the emissions limitations were based on the source with the highest level of emissions control for each of the nine source categories. These emission levels were then assumed to be implemented for every source in that category.

Under the Least Cost strategy, only three of the nine source categories implemented controls in order to ensure attainment of the short-term NO_2 standard. These three were: industrial coal-fired boilers, industrial oil- and gas-fired boilers, and industrial process units. (Table 5.3.6.1 shows the control levels implemented under the Least Cost option by source category.) Note that although utility boilers, gas turbines, and nitric acid plants contributed to violations of the short-term standard, the Least Cost Solution indicated that it was not cost effective to control these sources. Thus, in order to ensure full attainment with the 250 $\mu g/m^3$ short-term NO_2 standard, emissions limitations were needed for only the following three industrial categories:

Table 5.3.6.1

Control Levels Required under the Pure Least Cost Option by Source Category

Source Category	Control Level						
	0	1	2	3	4	5	Total
Utility Coal-fired Boilers							
• Number of Sources	21	0	0	0	0	0	21
• Control Costs (1,000s$)	0	0	0	0	0	0	0
• NO_x Emissions Reduced (lbs/hr)	0	0	0	0	0	0	0
Utility Oil- & Gas-fired Boiler							
• Number of Sources	11	0	0	0	0	0	11
• Control Costs (1,000s$)	0	0	0	0	0	0	0
• NO_x Emissions Reduced (lbs/hr)	0	0	0	0	0	0	0
Industrial Coal-fired Boilers							
• Number of Sources	90	0	0	1	6	0	97
• Control Costs (1,000s$)	0	0	0	16	1726	0	1742
• NO_x Emissions Reduced (lbs/hr)	0	0	0	129	676	0	805
Industrial Oil- & Gas-fired Boilers							
• Number of Sources	454	0	0	7	68	0	529
• Control Costs (1,000s$)	0	0	0	56	18785	0	18840
• NO_x Emissions Reduced (lbs/hr)	0	0	0	114	2494	0	2607
Gas Turbines							
• Number of Sources	11	0	0	0	0	0	11
• Control Costs (1,000s$)	0	0	0	0	0	0	0
• NO_x Emissions Reduced (lbs/hr)	0	0	0	0	0	0	0
Internal Combustion Engines							
• Number of Sources	0	0	0	0	0	0	0
• Control Costs (1,000s$)	0	0	0	0	0	0	0
• NO_x Emissions Reduced (lbs/hr)	0	0	0	0	0	0	0
Industrial Process Units							
• Number of Sources	103	2	0	1	10	0	116
• Control Costs (1,000s$)	0	14	0	20	886	0	920
• NO_x Emissions Reduced (lbs/hr)	0	93	0	4	220	0	318
Nitric Acid Plants							
• Number of Sources	8	0	0	0	0	0	8
• Control Costs (1,000s$)	0	0	0	0	0	0	0
• NO_x Emissions Reduced (lbs/hr)	0	0	0	0	0	0	0
Municipal Incinerators							
• Number of Sources	3	1	0	0	0	0	4
• Control Costs (1,000s$)	0	0	0	0	0	0	0
• NO_x Emissions Reduced (lbs/hr)	0	780	0	0	0	0	780

Source Category	Emissions Control Technology Level *
Industrial Coal-fired Boiler	4
Industrial Oil & Gas-fired Boiler	4
Industrial Process Units	4

* Levels correspond to technologies described in Tables 2.4.3.1 through 2.4.3.7, Section 2.4, Chapter 2.

At these emission levels, all receptors were brought into compliance with the short-term NO_2 standard. The estimated control costs associated with this strategy were $94 million.

5.3.7 Simple Rollback

Two levels of rollback are presented in Table 5.3.2.1. It can be seen that in order to attain the short-term NO_2 standard at all receptors, a 90 percent reduction of emissions is needed under a rollback strategy. (The 80 percent reduction results in violations at six receptors.) By definition, all relevant sources are controlled under the rollback strategy. This high degree of over-control is accompanied by annual costs of control amounting to $254 million.

By way of comparison, we also examined the cost and effectiveness of a strategy which requires every source to implement the maximum feasible level of control (i.e., the highest level of control shown in Tables 2.4.3.1 through 2.4.3.7, Section 2.4, Chapter 2). Essentially, this approach is comparable to the situation in which all sources were required to reduce emissions by 90 percent regardless of the source's specific impact on air quality. Thus, the costs associated with this strategy were approximately the same as those associated with the 90 percent simple rollback strategy ($254 million annually). Note, that this amounts to approximately twelve times the costs associated with the Least Cost strategy.

5.4 Results for a 500 $\mu g/m^3$ NO_2 Standard

The previous results have been keyed to the attainment of a 250 $\mu g/m^3$ NO_2 standard. The simulation model was also run using a short-term standard of 500 $\mu g/m^3$. While we have not presented these results in tabular form, a few generalizations can be stated.

A 500 $\mu g/m^3$ short-term NO_2 standard poses a far less severe attainment problem than a 250 $\mu g/m^3$ standard. Ambient modeling studies of the Chicago AQCR indicate that very few violations occur at a standard of 500 $\mu g/m^3$. Those violations that do appear are associated with small pockets of highly concentrated NO_x emissions sources.

Thus, it appears that if a 500 $\mu g/m^3$ standard were promulgated, the best control strategy would probably entail direct regulation of problem sources. The Least Cost strategy indicated that the costs associated with attaining a 500 $\mu g/m^3$ short-term standard were in the neighborhood of $1 million annually. This is to be contrasted with a strategy such as RACT that does not distinguish between sources contributing to violations and those that do not. Such strategies would cost millions of dollars per year, and would not even ensure attainment of the higher standard.

5.5 Conclusions

The results we have reported in this chapter show once again what has been amply demonstrated in studies of the cost and effectiveness of control of other pollutants: Strategies that exploit emission control cost differences and meteorological dispersion differences are vastly less costly than those which do not. Our results show that there may be differences of one order of magnitude or more between the cost of the most efficient strategies and the cost of the crudest strategies. Admittedly, the strategies which yield this large difference are at the limits of what is reasonable to consider. Nonetheless, these results are informative in several respects. In particular, the least cost results show the best that can be done given our meteorological and technological assumptions and given an ambient standard. The maximum control results show what could happen if the current ambient standard approach to air pollution control were abandoned in favor of the technical maximum approach now embodied in our water pollution control laws.

Another important feature of our results is that they show clearly that the attainment of short-term ambient standards for NO_2 is dependent upon the development (relative to what is available today) of advanced NO_x emission control technology. The emissions control technologies required to achieve emissions limitations sufficient to meet ambient standards are for the most part what are termed in Chapter 2 "Level 4" technologies. These technologies are projected to be available at the earliest sometime between 1981 and 1985 (see Tables 2.4.3.1 through 2.4.3.7, Section 2.4, Chapter 2). This is one of the important technological assumptions we have made, and this assumption will have an important bearing on our analysis of policy instruments for implementing these strategies discussed in the next two chapters.

Another conclusion that follows from our results is that a standard of 250 $\mu g/m^3$ implies sharply rising marginal costs of attainment.

Comparing the estimated least cost of attainment of a 500 $\mu g/m^3$ standard of approximately \$1 million with an estimated least cost of attainment of 250 $\mu g/m^3$ of approximately \$21 million, we infer that the approximate marginal cost in Chicago per $\mu g/m^3$ standard is \$80,000 [i. e., ($\$21 \times 10^6 - \$1 \times 10^6) \div 250$]. If we were passing judgment on the economic efficiency of the level at which standards are set, this is the number we would want to compare with estimated marginal benefits of ambient concentration reductions over the same range of ambient concentrations. [1]

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[1] Note that the figure of \$80,000 is an "average" marginal cost over a very wide range. It is likely that, at 250 $\mu g/m^3$, marginal cost is substantially higher than \$80,000. For example, if total costs increase at a constant exponential rate between 500 and 250 $\mu g/m^3$, then marginal cost at 250 $\mu g/m^3$ would be approximately \$256,000.

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APPENDIX A TO CHAPTER 5

A MATHEMATICAL DESCRIPTION OF THE EEA MODEL

The EEA Model is a variation of what has come to be known in operations research as the Knapsack Problem.[1/] In describing the programming problem, the following notation will be used:

i = an emissions source.

N_s = total number of sources.

t_i = control technology applied to source i.

k = technology level.

$klast_i$ = "highest level" of control technology applied to source i.

j = receptor.

N_r = total number of receptors.

Hr_i = hourly rate of emissions at source i (10^6 Btu/hr.).

$Hours_i$ = total hours of operation per year of source i.

D_{ij} = contribution at receptor j due to source i.

S = ambient air quality standard.

B_j = contribution at receptor j due to background and area sources.

$C_{t_i k}$ = increase in capital cost rate associated with moving from technology $k-1$ to technology k at source i.

$OM_{t_i k}$ = increase in operating and maintenance cost rate associated with moving from technology $k-1$ to technology k at source i.

1/ See, Senju and Toyoda (1968), Toyoda (1975), and Zanakis (1977).

$P_{t_i k}$ = increase in percent of total emissions controlled associated with moving from technology k-1 to technology k at source i.

Control Costs. The incremental annualized cost (AC) to source i of moving from technology k-1 to technology k is calculated as follows:

$$(1) \qquad AC_{t_i k} = (.16\, C_{t_i k} HR_i) + (OM_{t_i k} Hours_i Hr_i)$$

Note that the calculation assumes a capital recovery rate of 16 percent per year. Furthermore, it should be noted that capital costs are a function of Btu's per hour, while operating and maintenance costs are a function of Btu's per year.

Given Equation (1) the total annualized cost (TAC) for source i to achieve the level of control technology denoted by "$klast_i$" can be expressed as follows:

$$(2) \qquad TAC_i = \sum_{k=0}^{klast_i} AC_{t_i k}$$

This is simply the sum of the increased annualized costs of applying all control technologies up to and including the "highest level" actually employed. Thus, if $klast_i = 0$, source i is uncontrolled and the costs of control are assumed to be zero. 1/

1/ Note that $klast_i$ is an integer variable. In the programming problem, $klast_i$ can take on any integer value between zero ("no control") and five (the assumed "highest level" of control).

Air Quality. The impact (denoted below by "Impact") of source i on the air quality of the region can be expressed as a vector of dimension N_r, the number of receptors. First, we calculate the impact of source i at receptor j:

$$(3) \qquad \text{Impact}_{ij} = D_{ij}\left(1 - \sum_{k=0}^{\text{klast}_i} P_{t_i k}\right)$$

This states that the impact is represented by the contribution at receptor j due to source i multiplied by the percentage of total emissions that remain uncontrolled.

Second, we calculate the ambient air quality (denoted by "Result") at receptor j as follows:

$$(4) \qquad \text{Result}_j = B_j + \sum_{i=1}^{N_s} \text{Impact}_{ij}$$

The ambient air quality at receptor j is equal to the background and area source contributions plus the sum of the impacts of the individual emissions sources.

The change in air quality (denoted by "Delta") at receptor j due to source i associated with moving from technology k-1 to technology k at source i can be expressed as:

$$(5) \qquad \text{Delta}_{ij} = D_{ij} P_{t_i k} \qquad j = 1, \ldots, N_r$$

The Problem. Using the conventions explained above, the problem can be stated as minimizing the following objective function:

(6) $$\sum_{i=1}^{N_s} TAC_i$$

This is the sum over all sources of the total annualized costs for controlling each source.

The constraint on the minimization problem can be written as:

(7) $$Result_j - S \leq 0 \qquad j = 1,\ldots,N_r$$

This states that the ambient air quality at each receptor must be less than or equal to the ambient standard.

The Solution. To begin the program, $klast_i$ is set equal to zero for all sources. This corresponds to no control on all sources. The Impact and Result vectors are then given by:

(8) $$Impact_{ij} = D_{ij} \qquad j = 1,\ldots,N_r$$

(9) $$Result_j = B_j + \sum_{i=1}^{N_s} D_{ij} \qquad j = 1,\ldots,N_r$$

Thus, the result vector is used to represent the present level of air quality at each receptor. We then define a limit vector (denoted by "Limit") that contains the individual receptor standards. In our problem we are assuming one uniform standard, hence:

(10) $$Limit_j = S \qquad j = 1,\ldots,N_r$$

Next, we define a vector that represents the difference between the Result vector and the Limit vector at each receptor and designate this vector as Extra. This vector represents the amount by which each receptor is in violation of the standard; it contains no negative entries:

$$(11) \qquad \text{Extra}_j \begin{cases} = \text{Result}_j - \text{Limit}_j, & \text{if Result}_j > \text{Limit}_j \\ = 0 \qquad , & \text{if Result}_j \leq \text{Limit}_j \end{cases}$$

The program then proceeds to pick and apply control technologies to each source in an effort to bring all receptors into compliance with the ambient standard. This occurs when the Result vector lies within the feasible region. (See Figure 1, which depicts a two-receptor case.)

Specifically, at each source, the next highest level of technology is considered. First, the projection (Projection) of the Delta vector on the Extra vector is calculated:

$$(12) \qquad \text{Projection}_i = \sum_{j=1}^{N_r} \frac{\text{Delta}_j \ \text{Extra}_i}{\| \text{Extra}_j \|}.$$

This gives the total amount that the Extra vector would be "shortened" if the next "highest level" of technology were applied to source i. (See Figure (2).) Since Extra_j is a common term in all the projection calculations, it can be removed. This leaves simply the dot product (Dot) of the Delta vector and the Extra vector:

Figure 1

Diagrammatic Representation of Programming Problem
(Two-Receptor Case)

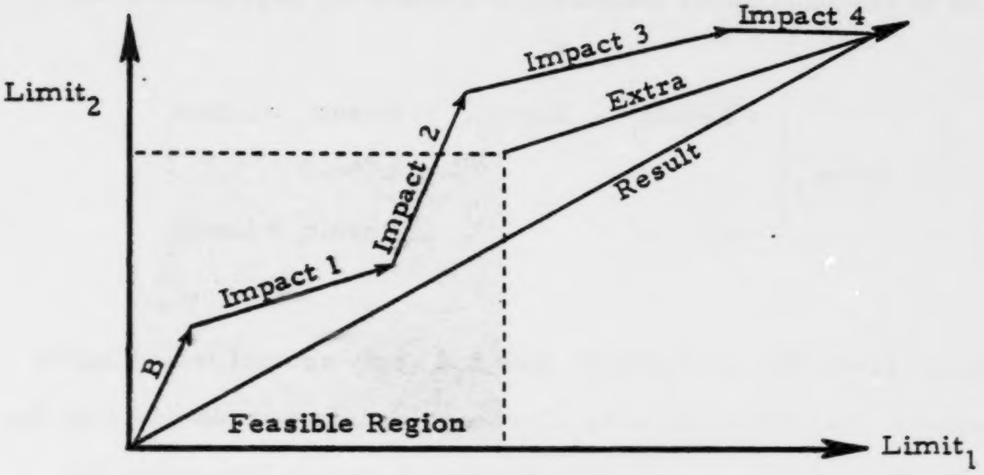
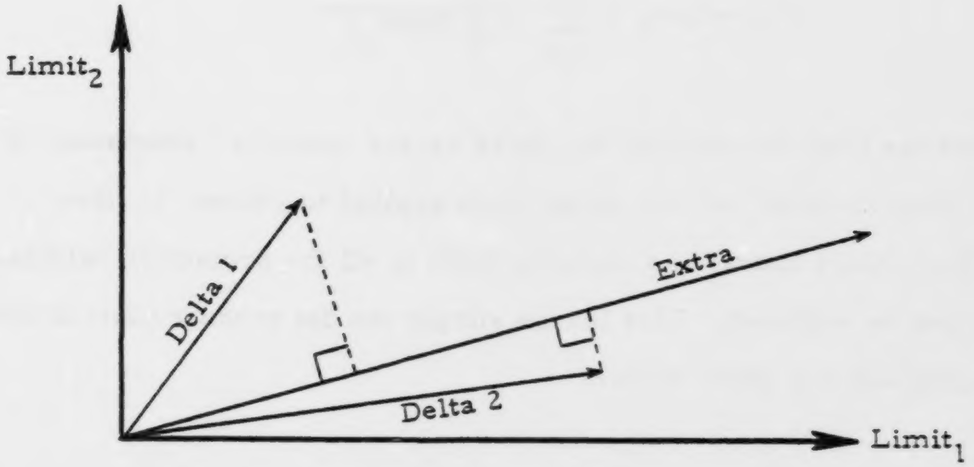

Impact 4
Impact 3
Limit$_2$
Extra
Impact 2
Result
Impact 1
B
Feasible Region
Limit$_1$

Figure 2

Projection of the Delta Vector on the Extra Vector
in Programming Problem


Limit$_2$
Extra
Delta 1
Delta 2
Limit$_1$

(13) $$\mathrm{Dot}_i = \sum_{j=1}^{N_r} \mathrm{Delta}_j \, \mathrm{Extra}_j$$

Finally, we define the gradient vector (G) as:

(14) $$G_i = AC_{t_i k} / \mathrm{Dot}_i$$

This expression represents the relative cost of shortening the Extra vector by a unit when the next "highest level" of control technology is applied to source i. Once a gradient is calculated for each source, the lowest one is chosen and applied. This process is repeated until one of two possible outcomes occurs:

1. The Extra vector equals zero.
2. The "highest level" of control technologies has been applied to all sources.

If (1) occurs, a least-cost solution has been reached. If (2) occurs, the problem is infeasible and no solution can be found. That is, the standard cannot be met at all receptors given the available control technologies.

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APPENDIX B TO CHAPTER 5

A DYNAMIC APPROACH FOR TRANSLATING AMBIENT NO_X CONCENTRATIONS FROM POINT SOURCES INTO NO_2 CONCENTRATIONS

1. Introduction

Ambient NO_2 formation due to combustion operations is a complex phenomenon dependent on several factors, the most important being: (1) the initial NO_x concentration; (2) the rate of plume diffusion and mixing; and (3) the ambient concentration of ozone and reactive hydrocarbons. 1/

Several approaches have recently been used to translate the ambient concentrations of NO due to point sources (as estimated by dispersion modeling) into NO_2 levels. One of these assumes that the maximum NO_2 level observed at any receptor in an area around a point source approximates a fixed fraction of the maximum concentration of NO_x at the receptor, irrespective of the above conditions. 2/ The fraction is derived from either the ratio of measured NO_2 to measured NO_x at a receptor influenced by a point source, or by correlating estimated NO_x and NO_2 concentrations at a receptor. While this approach may be sufficient for estimating the maximum impact of individual point sources at a single location, it is not valid for assessing the impact on air quality at a receptor due to several interactive point sources. This follows because the degree to which multiple sources impact a receptor varies with plume travel time to a receptor, and the ratio

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1/ A more detailed discussion of NO_2 formation in the atmosphere can be found in EEA (1978b).

2/ See, for example, EEA (1978a).

of NO_2 to NO_x in the plume changes continuously, especially during the first thirty to sixty minutes of plume discharge.

A second approach for estimating the NO_2 concentrations from isolated point sources assumes that, except for the initial conversion of NO to NO_2 due to thermal oxidation (about ten percent), further conversion of NO is limited by the ambient levels of ozone. Thus, the NO_2 concentration at a receptor due to an isolated source is expressed as:

$$\underset{\text{(concentrations at a receptor, ppm)}}{NO_2} = \underset{\text{(concentrations at a receptor, ppm)}}{0.1\,NO_x} + \underset{\text{(concentrations in the vicinity, ppm)}}{O_3} \tag{1.1}$$

This approach also has several limitations. Measured ambient NO_2 concentrations due to point sources are often higher in winter than in summer despite the fact that ozone levels are highest in summer. This suggests that ozone is not the only limiting factor in the conversion of NO to NO_2. It also seems likely that the NO_2 formation due to thermal oxidation in the first few minutes of plume discharge accounts for a major portion of measured NO_2 concentrations when ground level NO_x concentrations from point sources are at the maximum during conditions of poor atmospheric mixing or conditions involving short travel times. Under such conditions, the conversion of NO in the plume due to ozone is less significant. Furthermore, the initial thermal conversion of NO to NO_2 could be higher than ten percent of the initial NO_x levels. This conversion is primarily a function of the NO_x concentrations in the stack gas. It is not limited by oxygen concentrations, but rather by the unfavorably high temperatures. 1/

1/ The concentration of oxygen in most flue gases is on the order of 30,000 ppm; whereas, the NO_x levels are usually less than 1,000 ppm.

The NO to NO_2 conversion can be represented by the following two-step reaction mechanism: [1]

$$NO + O_2 \Longrightarrow NO_3$$

$$NO_3 + NO \Longrightarrow 2NO_2$$

The effect of high temperature on the reaction is to decrease the equilibrium concentration of NO_3, thereby limiting NO_2 formation. [2] Once the plume discharges into the atmosphere, lower temperature and additional oxygen results in rapid conversion of NO to NO_2 at a rate proportional to the square of the NO concentration. At NO concentrations above 100 ppm, the oxidation of NO by oxygen is quite rapid; it slows down as the NO concentrations reach 1 ppm. [3]

As a plume disperses, or as its travel time increases, the rate of NO conversion is controlled by the level of oxidants. Given sufficient time, almost all NO in a plume should be converted to NO_2 due to recurring encounters with fresh parcels of oxidant-containing air. The depletion of ozone is complete during the absence of ultra-violet radiation. However, in the presence of sunlight, a photochemical equilibrium between NO, NO_2, and ozone is established. This would lead to erroneous results if the highest daily O_3 concentrations were used in this approach (they occur during periods when the solar UV-flux is maximum) since total conversion of NO to NO_2 would be implied at the same time that photodissociation of

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[1] See EEA (1978b).

[2] See EPA (1971).

[3] Plume centerline NO_2 concentrations within one to two minutes of discharge have been reported in the Four-Corners Power Plant plume studies. See Megg _et al_. (1977) and Davis _et al_. (1974).

NO_2 were maximized. Furthermore, the presence of other oxidizing radicals in both summer and winter atmospheres are not accounted for by the measured O_3 concentrations.

Nevertheless, one might be able to predict the order of magnitude of NO_2 concentrations due to isolated point sources in the summer using this approach. Assuming little seasonal variation in the peak NO_2 concentrations, the predicted NO_2 concentrations could be considered a "worst case" estimate of the impact of a point source during a year. However, this has been tested only on a limited basis and its verification with observed NO_2 concentrations is yet to be shown. Finally, it should be reiterated that this approach is only applicable to isolated sources. It is incapable of assessing the interactive impact of multiple sources since it does not account for the variation in the ratio of NO_2 to NO_x with travel time in a plume.

2. Suggested Approach

The approach suggested here involves predicting the NO_2/NO_x relationship in individual plumes at different points in time for a given set of meteorological conditions and background oxidant levels. The relationships are developed for those meteorological conditions and oxident levels at which the highest NO_2 concentrations due to point sources have been observed.

Specifically, the NO_2 concentration in a plume at time t is assumed to be represented by:

$$NO_2\,(\text{ppm}) = f[\text{initial } NO_x\,(\text{ppm}),\ \text{plume diffusion, ambient oxidant concentrations (ppm), solar UV-flux, plume travel time } t\,(\text{minutes})]\ .$$

For a given set of meteorological conditions and ambient oxidant concentrations, the NO_2/NO_x ratio at time t in an individual plume is assumed to be primarily a function of the initial NO_x concentration:

$$(NO_2/NO_x)_t = f[\text{initial } NO_x \text{ (ppm), plume travel time } t \text{ (minutes)}]$$

The general shape of the curve relating the ratio NO_2/NO_x to plume travel time based on several power plant plume studies is shown in Figure 2.1. Curve B approximates the impact of higher NO_x emissions on the NO_2/NO_x relationship in a given plume. At higher NO_x emissions, initial NO conversion is faster since the rate of conversion is proportional to the square of the NO concentration. Later, as the plume diffuses, the amount of NO converted to NO_2 is limited by the level of mixing. Higher initial NO_2 levels may balance the higher initial NO_x concentrations and result in approximately the same NO_2/NO_x ratios for different NO_x emissions levels as time t increases. This can be seen by reviewing the reaction kinetics during the initial oxidation from plume studies.

Mathematically, the NO_2/NO_x ratio in a given plume after travel time t, can be expressed as:

$$(2.1) \qquad NO_2/NO_x = a \ln(\beta t^n + c)$$

where "a" and c are constants that depend upon the initial and final conditions and β is a function of the initial NO_x concentration in the plume.[1]

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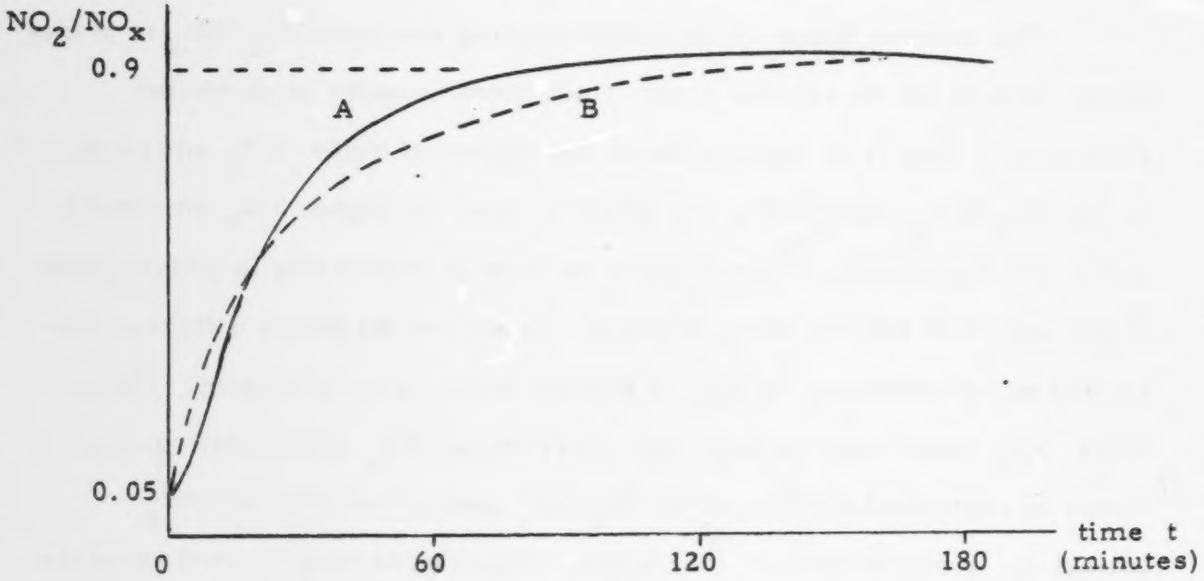
[1] The value of β can be derived by correlating the 50 percent NO to NO_2 conversion time measured in different plumes (under similar meteorological conditions and ambient ozone levels) to the initial NO_x concentrations in the plumes. If sufficient data are not available, the impact of varying initial NO_x concentrations on the NO_2 levels can be theoretically estimated from the thermal oxidation rate of NO.

Figure 2.1

Relationship Between NO_2/NO_x and Plume Travel Time



The following constraints are assumed to apply to all point sources under meteorological conditions and background oxidant levels that have been observed to result in maximum ground level NO_2 concentrations:

at $t = 0$, $NO_2/NO_x = 0.05$ (that is, the NO_2 concentrations in all combustion products before they are exhausted into the atmosphere are equal to about five percent of the initial NO_x levels)

at $t = 120$, $NO_2/NO_x = 0.05$ (that is, after two hours, the plume diffuses sufficiently that almost all the NO in the plume is converted to NO_2 by repeated mixing with fresh parcels of oxidant-containing air.) [1]

Data from various power plant plume studies during periods with adverse meteorological conditions and high oxidant levels can be used to determine the influence of these factors on the shape of the curve over various NO_x emissions levels.

3. Example

For a power plant plume under moderate mixing conditions (stability class C and wind speed of 5 meters/sec) and ambient oxidant levels of 0.2 ppm, the NO_2/NO_x relationship in the plume at any time t is:

$$(NO_2/NO_x)t = 0.5 \ln(0.5t^{\frac{1}{2}} + 1.11)$$

This relationship is based on the following constraints:

NO_2/NO_x at $t_0 = 0.05$, $t_{16} = 0.5$, $t_{60} = 0.8$, and

NO_x at $t_0 = 500$.

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[1] In an urban atmosphere characterized by high levels of reactive hydrocarbons, the ratio may never reach this value.

For any initial NO_x concentrations, the above equation can be generalized as:

(3.1) $$(NO_2/NO_x)t = 0.5 \ln(t\frac{1}{2} + 1.11)$$

where:

$$\beta = f(\text{initial } NO_x \text{ (ppm)}) \quad .$$

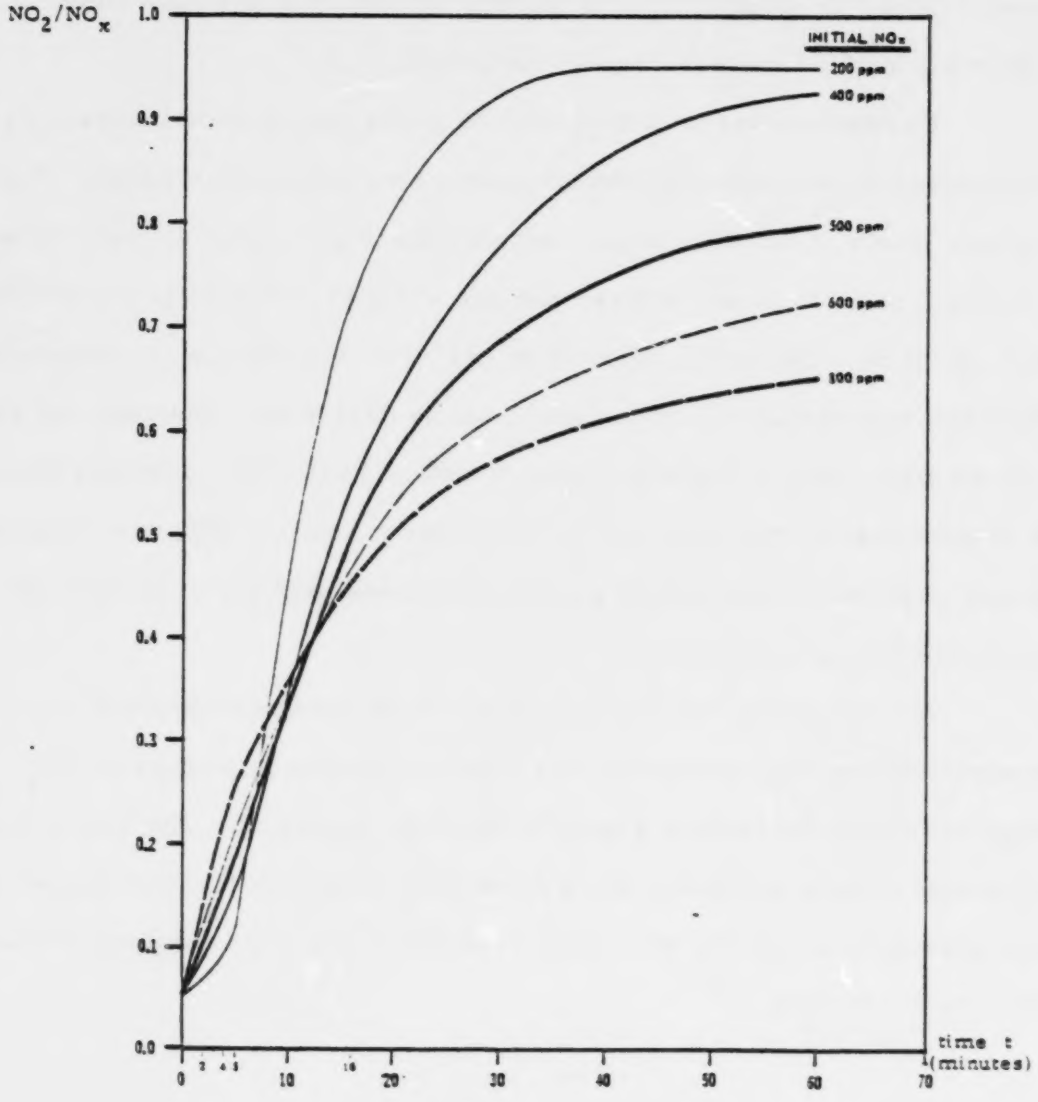
Equation (3.1) can be incorporated directly into the RAM dispersion model to translate estimated NO_x concentrations into NO_2 concentrations at different receptor locations. The underlying assumptions of this approach are conservative, but nonetheless, realistic. The boundary conditions at t = 0 and t = 120 should hold for all point sources during conditions when maximum NO_2 concentrations have been observed to occur. While, as noted, this approach may overpredict NO_2 levels from point sources in urban areas during conditions of significant photodissociation, in most urban areas, the highest NO_2 levels are observed in the morning or late afternoon when photodissociation is low. Since the approach allows for the temporal variation in the NO_2/NO_x ratios in a plume, it provides a more realistic estimate of the ambient NO_2 concentrations resulting from interacting multiple point sources.

4. Application

Figure 4.1 illustrates a series of NO_x to NO_2 translation curves corresponding to different initial NO_x concentrations in a plume. Lack of sufficient NO_2 and NO_x data for individual plumes under similar meteorological conditions prevented development of these curves from experimental data. The base curve A was derived from power plant plume studies

Figure 4.1

NO_2/NO_x Relationship in Point-Source Plumes with Different Initial NO_x Concentrations



with initial NO_x concentrations equal to approximately 500 ppm. Thermal oxidation was assumed to occur during only the first five minutes of plume discharge. Thermal conversion rates for the curves corresponding to the other initial NO_x concentrations were prorated from the base case, assuming similar meteorological conditions.

Further conversion of NO as the plume travel time increases is considered to be mainly dependent upon plume diffusion (mixing). For certain levels of ambient ozone concentrations and under similar meteorological conditions, only a fixed amount of NO is assumed to convert to NO_2 per unit time. However, because of resource constraints, a composite equation expressing all curves could not be developed. Instead, the specific curves were used to represent five ranges of initial NO_x concentrations. A limited test of this approach on short-term ambient NO_2 data from power plants resulted in reasonably good correlations between predicted and observed NO_2 concentrations.

In conclusion, we feel that this simple dynamic approach for translating the NO_x concentrations from point-source plumes to NO_2 concentrations represents a step in the right direction. The reactive photochemical models presently being developed were both too sophisticated and too expensive to use for this study because of the large number of sources that were analyzed.

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CHAPTER 6

DESIGN OF AN EMISSIONS CHARGE FOR STATIONARY SOURCE NO_x EMISSIONS

6.1 Introduction

In Chapters 4 and 5 we used a terminology that has come to be more or less common in describing the public administration of pollution control programs. We distinguished between "strategies" -- which are plans specifying levels of pollution control to be undertaken by sources, and "policy instruments" -- which are the means by which public administrators cause strategies to be implemented or adopted.

In the last chapter we examined the cost and effectiveness of alternative strategies for controlling stationary source emissions of NO_x to levels sufficient to meet short-term standards for NO_2. We found that strategies which take advantage of cost and/or meteorological differences between sources can attain ambient standards at substantially lower cost than can strategies which do not take account of these differences. In particular, we saw that a least cost strategy might be only a fourth as costly as a strategy that might be representative of current air pollution control strategies.

It would be unwarranted to conclude on the basis of our examination of the cost effectiveness of the strategies examined in Chapter 5, that a comparison of regulatory policies with economic policies will necessarily have a cost effectiveness relationship similar to that observed between the least cost strategy simulations and our regulatory simulations. While the strategies to which regulation leads are more costly than strictly necessary, there are many practical constraints on policy that influence what can and cannot be achieved in practice. In short, the policy instruments necessary to implement less costly strategies may be unavailable due to political or legal constraints, or may themselves be so costly as to offset any potential cost-saving advantage.

In this chapter, we begin our examination of the cost and feasibility of economic policy instruments for implementing air pollution control strategies. We shall focus on policy instruments which rely upon the use of charges of the type described in Chapter 3. We also consider the effect on cost and effectiveness of a number of specific design decisions that must be made in fashioning an emissions charge program. Our criteria for judging the relative merits of alternative design decisions will be the same as those applied to analysis of alternative strategies: cost and effectiveness.

Most of the calculations we shall present below are based on the strategy simulations reported in Chapter 5. Hence, no detailed consideration is given to the possible effects of uncertainty, to technological change or growth, or to emissions charges which vary by time of day, or in any other seasonal fashion. Our evaluation of the cost and effectiveness of emissions charges in this chapter thus is limited to the cost and effectiveness advantages of emissions charges over current regulatory policy, applied to existing stationary sources. We believe, however, that consideration of these additional factors would not result in material changes in our qualitative conclusions.

Some of our conclusions are, in light of the level of detail at which non-regulatory alternatives are usually discussed, at least mildly surprising. We find in Section 6.4, for example, that incentive rates stated in terms of dollars per unit of emissions alone may not induce emitters to reduce their emissions rates. This is because emitters may reduce their liability for incentive payments by reducing their hours of operation without reducing their emissions rates if a charge is based on emissions mass alone.

Another relatively surprising conclusion is the degree to which constraints on the extent to which incentive levels may be set on a source-by-source basis decrease the efficiency of incentive-based (or regulatory, for that matter) controls. We saw some hints that this would be the case in the previous chapter when we compared strategies that required uniform levels of emissions control from all sources in a class. What is surprising is just how sharply costs increase. In the limit, if an incentive based approach were adopted which applied a uniform charge rate to all stationary source emissions of NO_x, our analysis shows that the costs of control would be nearly as large as they are under the crudest possible control strategy, simple rollback. This result means that, on the basis of a comparison of emissions control costs alone, an important advantage of an incentive based approach to meeting ambient air quality standards may be lost IF incentive rates cannot differ to reflect differential scarcity of clean air at different locations and differential contributions to ambient concentrations.

It should not be concluded, however, that an incentives-based approach in which rates do not differ, reflecting the scarcity of clean air at different locations, are inferior (on the basis of cost-effectiveness) to regulatory approaches. The practical constraints which may make it difficult to implement a source-by-source charge also may make it difficult to implement a reasonably efficient regulatory policy. Even if both policies operate under similar practical constraints, there are still good reasons to prefer a policy based on charges to a regulatory policy. 1/ These reasons are, as is explained and analyzed in Chapters 3 and 4, that a charges approach will in general yield lower cost in the presence of uncertainty, will provide continuous impetus to environmental improvement, and will provide a continual stimulus to the development and application of new low-cost effective abatement technology.

The plan of the chapter is as follows. Section 6.2 lays out a basic design for a charge system based upon a mathematical programming analysis like that conducted in Chapter 5. Recall that we showed in Chapter 4 how the results of a mathematical programming analysis could be used to compute the charge rates required to induce adoption of a least cost strategy. Using the results of our mathematical programming analysis, we have computed the charge rates required for sources in Chicago in order to implement the least cost emissions control strategy. Section 6.2 reports the results of these computations.

In Section 6.3, questions related to the choice of quantity units to which incentives are to apply are examined. A number of alternative units have been discussed in the theoretical literature on charges, including contributions to emissions, inputs, and processes. Our analysis in Section 6.3 shows that charge rates applied to emissions, in practice, probably are best.

1/ We believe, as has been argued in Chapter 3, that regulatory policy operates under more stringent constraints, due -- in the main -- to its procedural complexity.

Another "units" design decision, which is analyzed in Section 6.4, is the choice of time dimensions of units chosen as the quantity basis for computation of liabilities for incentive payments. As noted above, this decision is not arbitrary. If this choice is made improperly, incentive based policy instruments will not induce the adoption of emission controls sufficient to attain ambient standards. Our analysis in Section 6.4 shows that the best approach is to define units in terms of maximum hourly emission rates.

Section 6.5 examines the question of "uniformity" of charge rates. The question addressed in this section is: "Should all sources face the same incentive rate, or should the rate distinguish between sources?" Our analysis in Section 6.5 concludes that it is desirable to adopt charge rates that differ as between sources, with differences related to differences in effect on ambient concentrations of NO_2. The amount of money that potentially can be saved if a charge system that distinguishes between sources is adopted is monumental.

The barriers to adoption of such charges are, of course, perceptions of equity and fairness. This problem is discussed in Section 6.6. Seemingly similar sources may face very different incentive rates. This may be hard (although not necessarily impossible) to "swallow," but the potential savings are so great that it is definitely worthwhile to search for ways to make such a system palatable. We offer some thoughts on this subject in Section 6.6.

Section 6.7 discusses the effect of alternative charge designs on the development of emissions control technology. We argue in this section that emissions charge programs which lead to relatively great expenditures for control and charge payments provide the greatest incentive to development of emissions control technology. The "cost" of this development, however, is greater outlays than are strictly necessary to attain and maintain ambient standards. There is thus a trade-off to be made between the rate and extent of development of new control technology and the cost of meeting ambient standards. We do not know exactly what values to place on these considerations, and thus we can come to no conclusions about this trade-off. However, we do show how a trade-off analysis might be performed based upon relative values we have inferred from our basic analysis.

In Section 6.8 we examine the costs that might be incurred by sources to carry out the record keeping and reporting tasks that would be required under an emissions charge policy. We find that the costs of the additional tasks that sources would have to perform (in addition to the tasks that would have to be performed under an effective regulatory policy) are _de minimus_.

Section 6.9 discusses some of the practical problems that must be faced in setting and adjusting charge levels. These problems, as our analysis in Section 6.9 will show, are not to be minimized. In particular, in order to set charges that will result in low cost attainment of ambient standards, the charge-setting authority needs to obtain accurate data on the relationship between control costs and emissions on a source-by-source basis. Even in an imaginary inflationless and static world, gathering this information would be a difficult task. It is well known that control costs can be subject to considerable variability, depending upon individual source characteristics. The problem is made even more difficult by the fact that economic growth, inflation, and technical change would all cause optimal charge levels to change. While we do propose some practical solutions to these problems in Section 6.9, it must be conceded that none of the solutions will eliminate uncertainty about important technical and economic parameters. A substantial degree of uncertainty is likely to remain.

Section 6.10 explores the costs of public administration of a charge program in relation to those of an effective regulatory program. Our general conclusion in this section is that the costs of public administration under all policy approaches are small in relation to emissions control costs. It is thus unlikely that they would, even if quite different from the estimates we report, change the relative ranking of policies on the basis of cost. Our findings suggest that a charges policy is no more expensive to administer than a regulatory one. The main reason for this is that a charges program designed along the lines we have discussed in this chapter should be less cumbersome to administer.

Section 6.11 briefly summarizes the conclusions of this chapter. The major conclusions, all of which have been described above, are these: First, designing a charge system on a source-by-source basis to take account of individual sources' contributions to ambient concentrations can save a large amount of money. These savings should be a substantial inducement to overcome the practical problems that would arise in implementing such a system. Second, the costs of implementing a charge system are likely to be of the same order of magnitude as the cost of implementing an effective regulatory policy, and perhaps slightly less in amount. Therefore, we do not believe that these costs (i.e., the costs of administering policy) would alter our basic conclusion that an emissions charge policy is a more efficient policy than a regulatory policy to implement pollution abatement. Third, an important difficulty in implementing an emissions charge policy will be obtaining accurate source-by-source cost information. While we propose some practical solutions to this problem, we believe that the agency's cost information will still be very imperfect.

6.2 A Basic Charge System

In Chapter 4 we showed how the results of a mathematical programming analysis could be used to calculate the emissions charge rates that would just induce sources to undertake the emissions limitations they would undertake under a least cost emissions limitation strategy. Accordingly, an ideal or "optimal" charge system would be based upon the type of procedures and computations described in Chapter 5, where we actually applied the tools of mathematical programming to find the least cost emissions control strategy.

To start our consideration of detailed design issues, let us suppose that our charge design called for us to carry out all of the steps discussed in Chapter 5 to provide the information needed to calculate the charge rates that would apply to each source. Figure 6.2.1 summarizes the way a charge program based upon the procedures discussed in Chapter 5 would operate. The main administrative tool in the charge program is the mathematical programming model. The inputs used in the programming model include an inventory of sources, dispersion modeling results, the air quality standard to be met, and cost of emission control data.

Figure 6.2.1

Flow Diagram Describing Agency Enforcement Duties in Emissions Charge Program

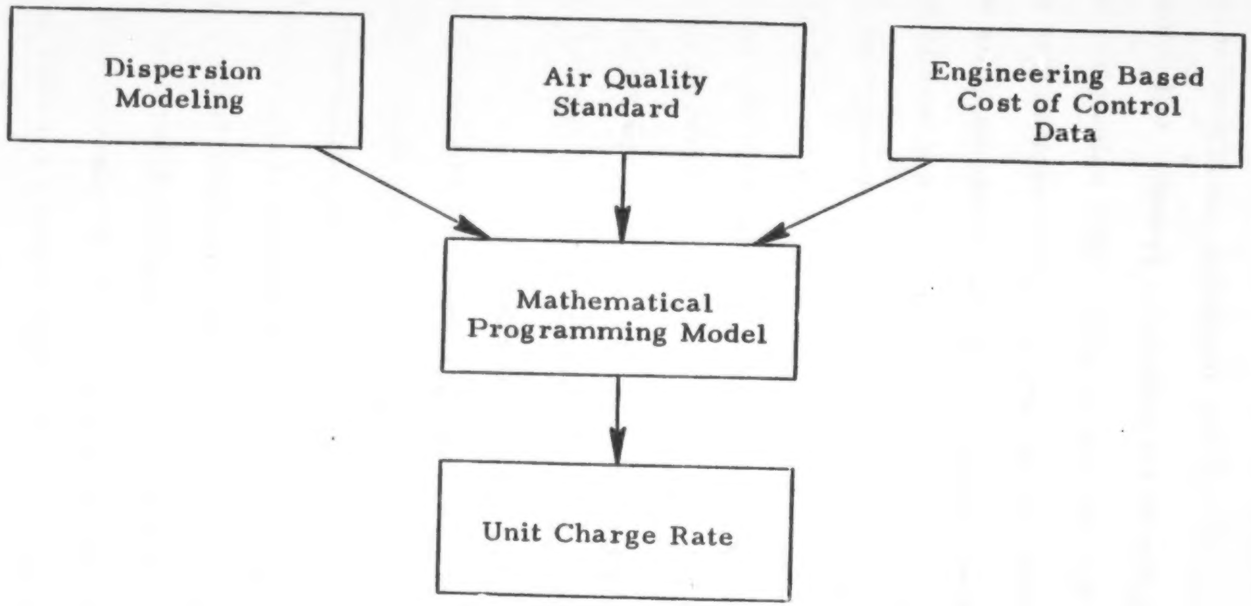

Dispersion Modeling
Air Quality Standard
Engineering Based Cost of Control Data
Mathematical Programming Model
Unit Charge Rate

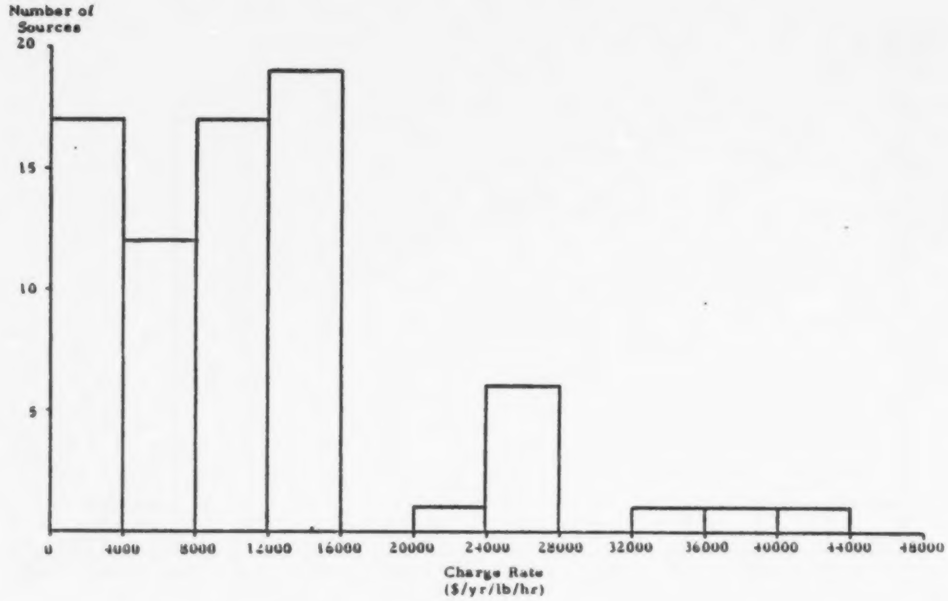
Figure 6.2.1 shows that the agency combines information on dispersion characteristics (from meteorological, stack, and emissions data), desired ambient air quality (including consideration of background levels and allowance for future industrial growth), and control cost data in order to determine the unit charge rate. This calculation is made simply by dividing incremental annual control cost of each source at the least cost solution by the corresponding incremental reduction in its emission rate.

We have made these calculations using the results of our optimization analysis of a least cost emission control strategy for Chicago. The results of these calculations are summarized in the histograms in Figure 6.2.2. As this figure shows, the charge rates necessary to implement the least cost solution vary considerably between sources. The range of charge rates is between \$62 and \$43,633 for industrial oil- and gas-fired boilers, \$51 and \$5,326 for industrial coal-fired boilers, and \$135 and \$4,238 for industrial process heat sources.

It is clear from the various panels in Figure 6.2.2 that the distributions of charge levels do not have "nice" properties. They are highly dispersed, and in many cases, are distinctly multimodal (i.e., have more than one peak). This means that classifying sources by major type (i.e., industrial oil-fired boiler, industrial coal-fired boiler, and industrial process) does not help very much to explain differences between charge levels. The differences we find thus must relate to still more detailed classifications of sources. We shall explore possible explanations for these differences below (see Section 6.5) in an effort to see whether or not it is possible to explain the dispersion of charge rates needed to implement an efficient pollution control program.

Figure 6.2.2

A. Histogram of Charge Levels for Industrial Oil Fired Boilers



B. Histogram of Charge Levels for Industrial Coal Fired Boilers

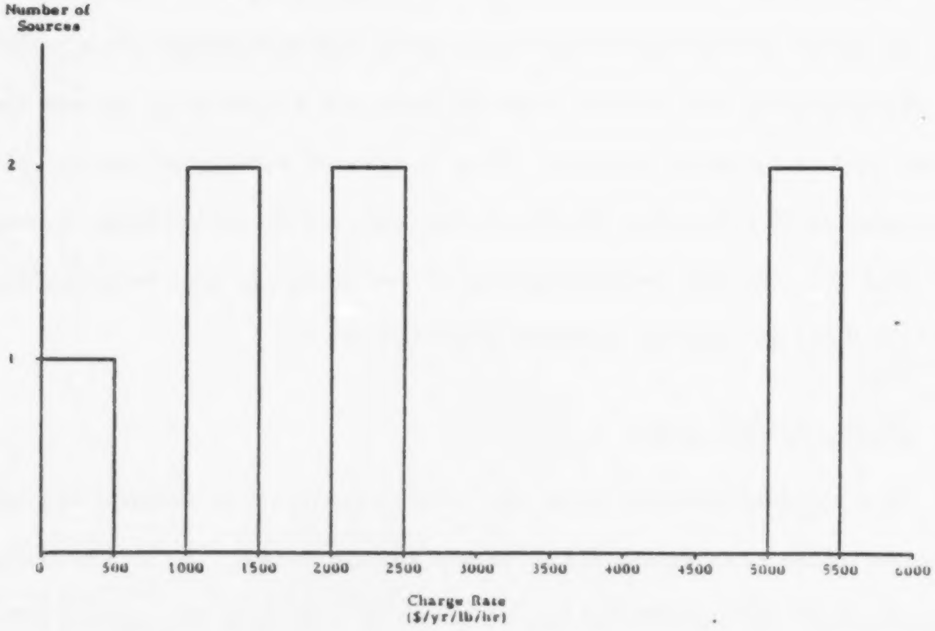
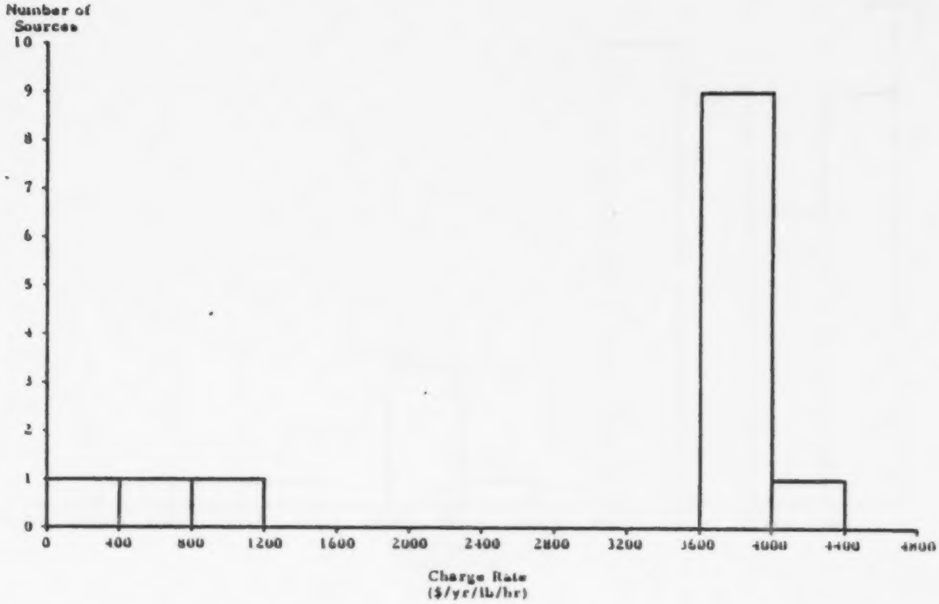


Figure 6.2.2 (Continued)

C. Histogram of Charge Levels for Industrial Process Heat Sources



Total annual payments under the charging scheme (i.e., payments on uncontrolled emissions) would amount to approximately $5.4 million, or about 25 percent of the control expenditures we estimate to be required under an optimal charge system. The ranges of estimated annual payments are between $478 and $434,584 for industrial oil-fired boilers, between $2,427 and $52,248 for industrial coal-fired boilers, and between $2,490 and $15,210 for industrial process heat sources.

6.3 Point of Application

The optimal charge rates we have calculated in Section 6.2 above are charge rates that would apply to emissions rates. Many investigations have suggested that consideration be given to applying charges at other points than emissions. For example, instead of applying our charges to emissions rates, charges could be applied to operation and/or process variables that correlate with emissions such as nitrogen content of fuel, flame temperature, firing type, or other parameters. The reason for considering these possibilities is that it may be easier to administer a system based upon charges applied to inputs or processes.

Our examination of technology for monitoring NO_x emissions (see Chapter 2, Section 2.5), however, concludes that adequate monitoring technology is available and is not a major cost factor. Moreover, we will show below that there are cost and effectiveness disadvantages of applying a charge to inputs or processes. In view of the fact that there are not likely to be significant savings in administrative costs associated with using process or input units, we conclude that charges should be applied directly to emissions.

There are three reasons supporting the conclusion that charges should be applied directly to emissions. First, as noted above, applying a charge to inputs or processes will result in total costs of emissions control that are higher than necessary to implement the emission reductions required to achieve ambient standards. Second, applying a charge to processes or inputs may lead to an incentive system that is not effective in inducing the adoption of emission control measures sufficient to meet ambient standards. Third, applying a charge to inputs or processes may provide no incentive to explore certain potentially economical emissions-reducing technologies.

Let us first examine the effect of choice of units on cost of control. To illustrate how the choice of a point for applying the charge affects control costs, consider the choice between applying a charge based on pounds of emissions and applying a charge based on fuel type.

Data for two hypothetical 800,000 kw plants operating 5,400 hours per year are shown below in Table 6.3.1. One of the plants burns oil, the other burns coal. As is clear from the table, the oil burning plant is both the more costly of the two, and the cleaner (in terms of total emissions of NO_x).

Faced with a choice between investing in these two plants, all other things being equal, it is clear that most firms would choose the coal fired plant. It produces the same output as does the oil fired plant, but it does so at a cost of approximately $25.8 million (i.e., $127.5 to $101.7) less per year than does the oil-fired plant.

Table 6.3.1

Hypothetical Model Plant Data

	Coal Fired Plant	Oil Fired Plant
Fuel Cost	$\$1.25/10^6$ Btu	$\$2.00/10^6$ Btu
Heat Rate	9,000 Btu/kwh	9,200 Btu/kwh
Emissions Factor	0.64 lbs $NO_x/10^6$ Btu	0.35 lbs $NO_x/10^6$ Btu
Annual Fuel Cost	$48.6 million	$79.5 million
Capital Cost for Plant	$332 million	$300 million
Annual Emissions	12,440 tpy	6,955 tpy
Annual Cost of Plant*	$101.7 million	$127.5 million

* Assumes an annualizing factor of 16 percent and that O&M costs other than fuel costs are zero.

If a charge on emissions were levied sufficient to induce investors in coal plants to install emission control technology that reduces emissions by approximately 40 percent, cost considerations would still favor choice of a coal fired plant.[1] Examination of the data reported in Chapter 2 (see Table 2.4.3.1) shows that, in order to achieve a 40 percent reduction in emissions, a coal fired plant could (in 1980 or after) utilize a low NO_x burner at an annual cost of $.008 per 10^6 Btu of annual heat input. For the hypothetical plant we are investigating, this translates into an estimated annual cost of $311,040. The incremental cost of achieving this level of emission reduction over and above the next lowest level of emission reduction available (which, we see in Table 2.4.3.1, is 22 percent) is determined by finding the annual cost of the lower level of reduction (which is $194,400; i.e., $.005 x 38.88 x 10^7) and subtracting from the cost of the 40 percent level (i.e., $311,040 - $194,400). This is $116,640. The increment in emissions reduced between these two levels of control technology is 18 percent (i.e., 40 - 22), or approximately 2,239 tons per year (i.e., 0.18 x 12,440). The incremental cost of control per ton reduced is thus approximately $52 per ton (i.e., $116,640/2,239). It follows that an emissions charge of approximately $52 per ton would be sufficient to induce investors in coal fired plants to install control technology which would reduce emissions by approximately 40 percent. The annual cost of the coal fired plant plus annual charge liability is approximately $102 million (i.e., $101.7 million annual cost of uncontrolled plant plus $0.3 million annual cost of control). This annual cost is still far below the annual cost of producing power via oil firing.

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[1] A 44 percent reduction would be needed to reduce emissions from a coal-fired plant to the same level as those from an oil-fired plant.

An alternative incentive-based approach that also would achieve approximately a 40 percent reduction in emissions would be to levy a charge on coal-fired plants (regardless of emission levels) sufficient to offset the cost advantage that coal-fired plants have over oil-fired plants in the production of power.[1] We saw above that the annual cost advantage of a coal-fired plant over an oil-fired plant of the size and operating characteristics of our hypothetical plant is approximately $25.8 million. A process charge of this level on operators of coal-fired plants would thus, accepting the assumptions of our example, suffice to induce investors to choose oil firing.

Both charges, an emissions charge of approximately $52 per ton and a process charge of approximately $25.8 million per year, achieve approximately a 40 percent emission reduction. Yet the cost to society of an emission control strategy implemented through a process charge on coal firing is $25.8 million, as against a cost to society of $311,040 if emissions control is implemented via a charge on emissions.

This example, artificial though it is, shows quite clearly how improperly defining the quantity units to which charges are applied can lead to huge excess costs of control. Refinement of a process or input charge to consideration of more parameters of emissions generation and diffusion (e.g., fuel type, burner type, flame temperature, excess air) could reduce the excess cost associated with process or input definitions of quantity units, but only at the cost of added complexity and, given the present state of knowledge about the generation of NO_x emissions, uncertainty.

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[1] We assume implicitly in this example that these are the only two economically relevant power generation technologies available.

The second reason (noted above) for a general presumption in favor of applying charges directly to emissions is that other choices may be ineffective in inducing sufficient emission controls. This is because the relationship between processes, inputs, and emissions are highly variable. Emissions testing data show that the correlations between process type and emissions and inputs and emissions are at best loose. Therefore, controls applied to processes or inputs would be a very uncertain way of achieving emissions reductions.

The third reason which weighs in favor of applying charges directly to emissions is that this will provide the strongest impetus to the development of less-polluting technology. If charges were applied to processes or inputs, little or no direct incentive would be created to find technologies that reduce emissions. For instance, in the case of the example process tax on coal firing examined above, no direct incentive would be created for any kind of stack emissions control technology development. There are, of course, some kinds of incentives based on processes and/or inputs that would provide limited and indirect encouragement to the development of emission control technology. For example, if a charge were levied on the nitrogen content of fuel, this would tend to reduce emissions and would provide an incentive for the development of fuel denitrification technology. It would not, however, provide any incentive to the development of stack gas cleaning technology. An emissions charge levied on emissions in contrast would provide incentives for the development of both fuel denitrification technology and stack gas cleaning technology, as well as any other technology which offered the prospect of economical emissions control.

We conclude that it is best in fashioning a charge system to apply to stationary source NO_x emissions to apply charges directly to emissions.

This conclusion accords with what we would anticipate purely on the basis of economic principles, and it is strongly supported by practical considerations as well.

6.4 Units of the Charge

One of the interesting (and perhaps novel) characteristics of the optimal system of charges we have calculated in Section 6.2 is that they apply to hourly emissions rates rather than simply to emissions (i.e., they are denominated as \$/lb/hr rather than simply as \$/lb). The reason that our charges are denominated thusly is that in order to meet a one-hour standard, we must (according to the diffusion assumptions we have made in Chapter 5) control one-hour emissions rates, and the charges based on emissions alone will not do this if operating rates (i.e., hours of operation per year) may be varied.

To understand why our charge rates must control for hours of operation, recall from Chapter 2 (see Section 2.4.3) that annual costs of control depend upon three factors. These factors are:

- size of the source (e.g., as measured by the heat rate for combustion sources)
- emission rate
- total emissions.

Representative data for two model plants which illustrate the various factors determining cost are shown in Table 6.4.1. Each model plant has the capacity to emit 100 pounds of NO_x per year and has a maximum designed operating rate of 8,000 hours per year. It is assumed that in order to

Table 6.4.1

Analysis of Emissions Charges Based on Operating Rate

A. **NO_x Emissions Characteristics**

- Maximum hourly NO_x emissions = 100 pounds
- Maximum annual operating rate = 8,000 hours

B. **Required NO_x Emissions Control System**

- Control efficiency = 85 percent
- Costs
  - Capital = $1,000,000
  - O&M = $0.05 per pound of NO_x emissions reduced

C. **Costs per Pound of Emissions Reduced**

	Plant A	Plant B
• Operating Rate	100%	50%
• Annual Capital @ 16% CRF	$160,000	$160,000
• Operating & Maintenance	$34,000	$17,000
Total Annual Costs	$194,000	$177,000
• Pounds of NO_x emissions reduced	680,000	340,000
• Costs per pound (¢/lb)	28.5	52.1

D. **Emissions Charge = 28.5¢/lb**

	Plant A	Plant B
• Pay charge, no controls	$228,230	$114,000
• Install controls		
- Annual Costs	$194,000	$177,000
- Charge Payments	$34,000	$17,100
	$228,230	$194,100

E. **Emissions Charge = 52.1¢/lb**

	Plant A	Plant B
• Pay charge, no controls	$416,800	$208,230
• Install controls		
- Annual Costs	$194,000	$177,000
- Charge payments	$62,520	$31,230
	$256,520	$208,230

ensure that the sources will not violate a one-hour NO_2 standard, emissions during any one-hour must be reduced by 85 percent. Furthermore, the capital costs of the associated emissions control systems are estimated to be $1,000,000 with operating and maintenance costs of $0.05 per pound of emissions removed.

The costs per pound of emissions reduction, if calculated on a per-year basis, would be a function of the plants' actual operating rates. In order to illustrate the importance of this, the operating capacities of the two plants in Table 6.4.1 have been specified such that Plant A operates at 100 percent capacity and Plant B operates at 50 percent of designed capacity. [1/] The annual costs associated with operating the emissions control system for Plant A are $194,000, while the annual control costs for Plant B are $177,000. Assuming that both plants operate their emissions control systems at the designed control efficiency, then Plant A removes 680,000 pounds of NO_x and Plant B removes 340,000 pounds of NO_x. Thus, the costs per pound of emissions reduced for the two plants would be 28.5¢ per pound and 52.1¢ per pound, respectively.

This example demonstrates that hours of operation must be considered if charges are to be expressed in terms of $/lb. All other things being equal, sources with relatively low operating rates will have relatively high incremental costs of control. This must be recognized by any system that attempts to base incentives on charges levied on emissions, as is demonstrated clearly in parts C, D, and E of Table 6.4.1.

[1/] This situation might be analogous to one pertaining to two utility boilers, one used for process steam and the other used solely for space heating.

If the level of an emissions charge were calculated on the basis of the highest load factor, Plant B would find it in its economic best interest to pay the charge without installing controls, thus violating the standard. This can be seen by comparing the costs that Plant B would incur if it pays the charge on its uncontrolled emissions ($114,000) with those it would incur if it installs controls and pays the charge only on its remaining emissions ($194,000).

We conclude from this example that charge rates must either incorporate a factor for operating hours to prevent sources from reducing their charge liabilities without taking measures to reduce their hourly emission rates, or be expressed in terms of emission rates as we have chosen to do.

6.5 Source Classifications for Incentive Rates

Data presented in Section 6.2 based on our calculations for Chicago illustrate vividly how varied charge rates may have to be in order to implement a least cost emission strategy. The charge rates we have calculated vary among sources in the same general classification by as much as a factor of approximately 700. We know that, on theoretical grounds, this result is not implausible. Recall that in Chapter 4, Section 4.2, we showed that the schedule of incentives needed to implement emission control at lowest total control cost requires a different incentive rate for each source. This can be seen by referring to equation (6.5.1) which shows that the charge rate for each source must be set on the basis of its contributions to ambient concentrations at all receptors in the air quality control region; i.e.,

$$(6.5.1) \qquad t_i = -\sum_{j-1}^{N_r} \lambda_j d_{ij} \qquad\qquad i = 1,\ldots,N_s$$

The optimum incentive rate varies from source-to-source because the d_{ij} vary from source-to-source. [1]

As a practical matter, differentiating incentive rates between sources may not be an efficient alternative. Undoubtedly it would be more costly and complex to set and keep track of appropriate charge rates for individual sources, although with the degree of automation possible today at low cost the extra cost, in our opinion, would not be very great.

A somewhat more serious potential difficulty is that a system featuring widely different incentive rates may not be acceptable from an equity standpoint. Differences in charges based upon difficult-to-estimate individual contributions to receptors may be viewed as essentially arbitrary in their discrimination between sources, and therefore unfair.

In this section we examine the costs of grouping sources together into categories for purposes of levying a charge. Our analysis will show that unless the system for categorizing sources recognizes both source characteristics and diffusion characteristics, the costs of categorization outweigh any conceivable cost-savings that might be realized from the greater simplicity associated with a system with just a few categories. We defer until the next section any discussion of equity considerations that might be affected by categorization of sources.

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[1] Recall from Chapter 4 that t_i is the charge rate to the i^{th} source and d_{ij} is the i^{th} source's contribution to ambient concentrations at receptor j per unit of emissions; λ_j is the "shadow price" of concentration at j. It should not be concluded that the necessity for source-by-source distinctions is unique to an efficient charge system. Efficient regulation, i.e., the enlightened regulation system discussed in Chapters 3 and 4 above, would also require source-by-source emissions standards.

6.5.1 The Extra Costs of Source Classification

To understand how categorization of sources results in excess costs above those required to implement a least cost emission control strategy, let us first examine the effect of departures from the "optimal" charge rate upon an individual source's cost of control.

If sources are cost-minimizers (the appropriateness of this assumption and the consequences of not adopting it are addressed in the Appendix to Chapter 3), each source will control its emissions to the point where its incremental cost of emissions reduction is just equal to its charge rate. That is, the i^{th} source will control to

$$-C_i'(e_i) = t_i \qquad i = 1, \ldots, N_s \tag{6.5.1.1}$$

where e_i denotes "emission reductions". Assuming that equations of the form of equation (6.5.1.1) can be solved for e_i as a function of t_i (sufficient conditions that insure that this can be done are that $C_i''(e_i) \neq 0$), we may rewrite the i^{th} source's cost of control function as

$$C_i(e_i(t_i)) \qquad i = 1, \ldots, N_s \quad (N_s = \text{number of sources}) \tag{6.5.1.2}$$

which shows explicitly the relationship between charge rates and emissions levels, and the total cost of control for all sources in an AQCR may be written as

$$\sum_{i=1}^{N_s} C_i(e_i(t_i)) \tag{6.5.1.3}$$

The difference in control costs at two different charge structures, $t_i^{'}$ and $t_i^{''}$, is then simply

$$(6.5.1.4) \qquad \Delta C = \sum_{i=1}^{N_s} \left[C_i(e_i(t_i^{'})) - C_i(e_i(t_i^{''})) \right]$$

We are in particular interested in the value of equation (6.5.1.4) when the two structures under consideration are some arbitrary t_i such that $t_i \neq t_i^*$, where t_i^* is the optimal charge (i.e., the charge that would induce adoption of the least cost emission control strategy.

For any source, we may develop an approximate expression for the excess costs induced by a non-optimal charge rate as follows. First, we obtain an approximate expression for control costs for t_i in the neighborhood of t^* by expanding in a Taylor series, obtaining

$$(6.5.1.5) \qquad C_i \cong C_{i*} + C_i^{'} \frac{de_i}{dt_i} (t_i - t^*)$$

The difference in control costs at t_i and t^* then is approximately

$$(6.5.1.6) \qquad C_i - C_{i*} \cong C_i^{'} \frac{de_i}{dt_i} (t_i - t^*)$$

To evaluate this expression, we note by differentiating equation (6.5.1.6) with respect to t_i that

$$\frac{de_i}{dt_i} = -\frac{1}{C_i^{''}}$$

Thus, our expression for the difference in costs between t_i and t^* is

$$(6.5.1.7) \qquad C_i(e_i(t_i)) - C_i(e_i(t^*)) = -\frac{C_i'}{C_i''}(t_i - t^*)$$

This approximation is easily illustrated by means of a numerical example. Consider the control cost function

$$(6.5.1.8) \qquad C = \exp\left\{21.6638 - 0.0544\ \mathrm{TPY}\right\}$$

which approximates the cost of control for a 250 x 10^6 Btu per hour oil fired boiler operating 5400 hours per year. The marginal control cost function corresponding to this function is given by

$$(6.5.1.9) \qquad C' = -0.0544 \exp\left\{21.6638 - 0.0544\ \mathrm{TPY}\right\}$$

and the derivative of the marginal cost function with respect to emissions in tons per year is given by

$$(6.5.1.10) \qquad C'' = 0.0030 \exp\left\{21.6638 - 0.0544\ \mathrm{TPY}\right\}$$

Suppose that a uniform (across all sources) charge rate of \$800 per ton (i.e., about 40 cents per pound) of NO_x emissions is established. Then, by setting marginal cost as shown by equation (6.5.1.9) equal to \$800, we find that the source in this example will emit approximately 222 tons per year. At this level of emissions, C'' is equal to 44.12, and

$$-\frac{C'}{C''} = \frac{800}{44.12} = 18.13$$

The last ingredient we need in order to estimate excess costs due to uniform charges is the difference between the uniform charge rate and the rate that would apply under a policy of source-specific charges. For illustrative purposes we have tabulated a number of different possible values for this difference in Table 6.5.1.1 and have computed approximate corresponding excess costs. In this particular example, excess costs are approximately equal to the percentage difference between the optimal rate and the rate shown in column (1) of the table times the total control cost shown in column (3). For example, we see in column (4) of this table that if a charge rate of $2000 is set and if this exceeds the optimal rate by 10 percent, then excess costs are approximately $3627.

As can be seen from Table 6.5.1.1, the excess costs of a non-optimal rate could be substantial. In general, the degree of excess costs depends upon two factors: the rate of change of costs with respect to emissions, and the rate of change of emissions with respect to incentive levels. The larger are these factors, the greater is the excess cost caused by a departure of the incentive rate from the optimal rate.

Table 6.5.1.1

Illustrative Approximate Excess Costs of Uniform Charge Rate

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Charge Rate ($/Ton)	Emissions TPY	Control Costs ($/Year)	Approximate Excess Control Costs in $/Yr at $(t_1 - t^*) \div t^*$				
			10%	20%	30%	40%	50%
2,000	205	36,765	3,627	7,253	10,880	14,507	18,133
1,500	210	27,574	2,720	5,440	8,160	10,880	13,600
1,000	218	18,382	1,813	3,627	5,440	7,253	9,067
800	222	14,706	1,451	2,901	4,352	5,803	7,253
700	224	12,868	1,269	2,539	3,808	5,077	6,347
600	227	11,029	1,088	2,176	3,264	4,352	5,440
500	230	9,191	907	1,813	2,720	3,627	4,533
400	235	7,353	725	1,451	2,176	2,901	3,627
300	240	5,515	544	1,088	1,632	2,176	2,720
200	247	3,676	363	725	1,088	1,451	1,813
100	260	1,838	181	363	544	725	907

6.5.2 Applying the Mathematical Programming Model to the Source Classification Question

In order to explore the possible excess costs for an entire air quality control region associated with establishing uniform charge rates for classes of sources, we have performed some experiments using our Chicago data and the mathematical programming model described in Chapter 5. In particular, we examined what would happen to emissions control costs under two different classification systems. Under the first system (which we call the "Uniform Charge" system), a single charge rate was levied on all sources. The level of the rate was set at the lowest rate that would induce sufficient control to meet a short-term standard of

250 $\mu g/m^3$. This level was determined to be approximately $25,000 per year per pound per hour. Under the second classification system examined (which we call the "Source Category" charge system), three different charge rates were set -- one for each of the three source classes that are controlled under the least cost emission control strategy. [1] These three charge rates were as follows:

Source Category	Charge Rate ($/lb of NO_x/hr)
Industrial Coal Fired Boilers	8,300
Industrial Oil & Gas Fired Boilers	25,000
Industrial Process Units	13,333

The results of these two exercises are shown below in Table 6.5.2.1. For purposes of making comparisons, we have also shown corresponding results for the Optimal Charge system in which charge rates are set at levels which would induce adoption of the least cost emissions control strategy. As can be seen from Table 6.5.2.1, both of the experiments result in substantial increases in control costs, substantial reductions in the aggregate hourly emission rate, and substantial increases in aggregate annual liabilities for charge payments. A Uniform Charge system results in estimated excess emission control costs (over

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[1] These rates were set equal to the highest average cost (per pound per hour) of emissions reduction in each source category under the least cost strategy.

Table 6.5.2.1

Effect of Source Classification on Emission Control Costs, Emission Rate Reductions, and Charge Liabilities

	Number of Sources Controlled	Emission Rate Reductions (10^3 lb/hr)	Control Costs (10^6 \$/yr)	Charge Payments (10^6 \$/yr)
Optimal Source-by-Source Charge Rates	96	5	21	5.4
Uniform Charge Rate of \$25,000/yr/lb/hr	790	105	239	468
Source Category Rates	742	29	94	75
Industrial Oil Fired Boilers - \$25,000/yr/lb/hr				
Industrial Coal Fired Boilers - \$8,300/yr/lb/hr				
Industrial Process Units \$13,333/yr/lb/hr				

the level of control costs for the Optimal system) of over $200 million per year, and a staggering annual liability for charges of $468 million per year. These large sums are a result of the fact that a uniform charge rate results in many sources controlling that do not need to control to meet ambient standards under the least cost strategy, and overcontrol of many sources that do control under the least cost strategy.

Excess control costs and charge payments are somewhat smaller under the Source Category charge, as is shown in the third line of the table. Setting rates by source category as we have done reduces excess control costs to slightly over $90 million per year, and reduces estimated annual charge liabilities to $75 million.

The retentive reader will note that control costs under the two source classification plans we have examined are close to control costs we calculated in Chapter 5 for strategies representing the range of designs of current regulatory policy. In particular, control costs under the Source Category charge are approximately $94 million, which is also the amount of control costs we have calculated under the Selective Emissions Control strategy. (Recall that we interpret the latter strategy as representative of what might emerge under a relatively sophisticated design of current regulatory policy.) Control costs under a Uniform Charge are estimated to be $239 million, which is nearly as large as the costs we have estimated for the Simple Rollback or Maximum Feasible Control. (Recall that these strategies also are interpreted as representing particular designs of current regulatory policy.)

It is tempting, but incorrect, to conclude from these results that incentives-based policy approaches enjoy little or no advantage over regulatory policies if incentive rates cannot differ between sources. To the contrary, economic policies still will enjoy the cost advantages that come from coping better with uncertainty (recall our analysis in Sections 3.5 and 4.3), and still retain their advantage in inducing the development and application of new emission control technology.

The conclusion that does follow from these experiments is that classification systems of the crude sorts we have examined (or other departures from optimal designs) are exceedingly costly. This certainly is no surprise given the wide dispersion of optimal charge rates depicted above in Figure 6.2.1.1.

It is possible that a more refined classification system (e.g., by burner type, etc.) along the dimensions mentioned in the preceding section would reduce excess control costs and annual charge liabilities. This possibility could be explored by performing statistical analyses of the relationships between the optimal charge rates we have calculated and possible classifying factors such as heat rate, stack height, burner type, fuel type, and so forth. If some combination of these factors explained a large portion of the variance in charge rates, then they form the basis for a more detailed classification system than those investigated above.

To illustrate how such an analysis might proceed, we have conducted a preliminary analysis of the relationship between optimal charge rates and some of the variables mentioned above for 21 of the least cost emission control strategy.[1] In this analysis, we have regressed the log of the optimal charge rate (which, recall, is equal to the marginal cost of control at the level of control needed to implement the least cost emissions control strategy) on the log of the uncontrolled emission rate divided by heat input, the log of the product of flow rate times temperature times stack height divided by stack diameter (as a proxy for effective stack height), and dummy variables representing different burner types, fuels, and sizes. The results of our regression are shown in Figure 6.5.2.1. As can be seen, the independent variables we have examined explain a high proportion (over 99 percent) of the variation in the log of the optimal charge rate for a subset of the industrial oil and/or gas fired boilers which control emissions under the least cost emission control strategy. Moreover, the signs of the explanatory variables that have interpretations (i.e., the explanatory variables other than the dummies) are in agreement with what one would expect. The negative sign associated with the log of (QRATE/HEAT) is explained by the fact that other things being equal, the lower is the uncontrolled emissions rate for a given heat rate, the smaller will be the incremental emissions rate reduction estimated to result from

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[1] At this writing, we did not have a complete and consistent copy of the emission inventory data used by EEA to obtain the results reported in Chapter 5 and analyzed here. The sample of 21 was pieced together from data we did have.

Figure 6.5.2.1

Estimated Regression Explaining Differences in Charge Rates

```
     LOG(MCC) = A0+A1*LOG(QRATE/HEAT)+A2*LOG(FLOW*TEMP*HEIGHT/DIAM)+A3*Z601+A
4
*Z602+A5*Z401+A6*Z702+A7*Z501+A8*Z502

NOB = 21      NOVAR = 9
RANGE =  1 TO 11,  17 TO 22,  29 TO 30,  36,  56
RSQ =   0.99927     CRSQ =   0.99879     F(8/12) =  2041.530
SER =   0.0747      SSR = 6.6966E-02     DW(0) =  2.03

COEF            VALUE           ST ER           T-STAT

A0             7.47463         0.39906         18.73040
A1            -1.15942         0.02165        -53.55710
A2             0.04756         0.02255          2.10882
A3            -0.51052         0.14484         -3.52473
A4            -0.38210         0.11666         -3.27532
A5            -0.46038         0.13732         -3.35265
A6            -0.27563         0.14864         -1.85440
A7            -0.41640         0.14767         -2.81972
A8            -0.47913         0.15879         -3.01731
```

where MCC = marginal cost of control, $/yr. = optimal charge rate

QRATE = uncontrolled emission rate, lbs/hr.

HEAT = design capacity, 10^6 Btu/hr.

FLOW = stack flow rate, acfm

TEMP = stack temperature, °F

HEIGHT = stack height, feet

DIAM = stack diameter, feet

Z601 = 1 if SCC is 10200601, 0 otherwise

Z602 = 1 if SCC is 10200602, 0 otherwise

Z401 = 1 if SCC is 10200401, 0 otherwise

Z702 = 1 if SCC is 10200702, 0 otherwise

Z501 = 1 if SCC is 10200501, 0 otherwise

Z502 = 1 if SCC is 10200502, 0 otherwise.

the application of an increment in emissions control technology level applied. Estimated incremental cost, in contrast, varies with heat input but not with uncontrolled emissions rate. Thus, we would expect sources with relatively large uncontrolled emission rates at given heat input rates to have somewhat smaller incremental costs than those with relatively low uncontrolled emissions rates at the given heat input rate, other things being equal. Our regression results confirm this expectation.

We would also expect the sign of the coefficient of log(FLOW * TEMP * HEIGHT/DIAM) to be positive, since this variable is a rough proxy for effective stack height. Again we see that the regression results are consistent with this expectation. Lower values of this variable are associated with higher charge rates, and vice versa.

This analysis suggests (it does not show because it is based on far too little data) that it may be possible to develop a more refined source classification system than the simple source category system described above which explains optimal charge rates in terms of variables that are easily understandable and directly related to the objective of efficient attainment and maintenance of ambient standards. To complete the analysis of our Chicago results begun above, the following additional steps would have to be performed:

- Test the ability to discriminate, based on these variables, between sources that would be subject to a positive charge and sources that would be subject to a zero charge.
- Test the ability to explain charge rates for industrial coal fired boilers and for industrial process heat sources.

On the basis of the results for the simple Uniform and Source Category systems we have examined, we must conclude that naive classification is extremely expensive. The gains from setting source-specific charges are so substantial as to outweigh any equity or administrative cost advantage of a classification system that we can conceive of. However, we must concede that it may be difficult to persuade the public at large that the advantages of a source specific approach outweigh the seeming unfairness of such a system. We shall have more to say about this below in our discussion of distributional considerations. However, statistical analyses of the sort illustrated above could do much to explain differences in charge rates in terms of factors that could be understood easily. They also could provide a basis for a more refined classification system.

6.6 Distributional Considerations

Our analysis of source classification in the preceding section brings squarely to the fore some of the most difficult issues that arise in designing an efficient emissions charge system -- considerations of how the costs of reducing pollution will be shared. Ultimately, the public will pay the costs of pollution control in the form of higher prices. Nevertheless, costs will not be distributed evenly across all consumers and producers. For example, analyses have shown that while a system of emissions charges can result in significantly lower total costs of control than a standard approach, it can result in relatively higher costs to polluters since they must pay for the pollution control equipment as well as the charges.[1] In turn, this could raise product-prices more than under a system of emissions standards. [1]

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[1] See Anderson and Ferrar (1975).

This so-called "double-burden" argument is often put forth as an argument against emission charges. The fact that charge rates, if charges are to be an efficient policy instrument for implementing emission controls, must differ between sources is another distributional argument that is often made against charges.

Our economy is so complex that it is impossible to be really certain about who ultimately will be a net beneficiary and who will not of any given policy. The most that can be accomplished given available information is to analyze the direct incidence of alternative forms of charge. This is done in Section 6.6.1 of this chapter. We shall see in that section that the optimal charge system is less burdensome than any other charge system we have considered and less burdensome than the regulatory baseline system. We shall also show in Section 6.6.2 that there are a variety of ways in which arrangements can be made to achieve "acceptable" direct distributional effects while preserving most of the efficiency advantages enjoyed by a system that takes account of diffusion differences between sources.

6.6.1 First-Order Distributional Effects of Alternative Emissions Charges

The starting point for our examination of direct distributional effects is an estimate of the sizes of the sum of annual charge liabilities and control costs under the different charge designs we have examined. Adding estimated control costs and liabilities reported in Section 6.5, we obtain the estimated sum of annual charge liabilities and control costs shown below in Table 6.6.1.1. Table 6.6.1.1 shows that this sum is smallest ($26.4 million in amount) for the optimal charge system, next smallest ($169 million in amount) for the charge system which distinguishes between (but not within) source types, and greatest ($707 million in amount) for the uniform charge system.

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[1] Economic theory tells us that a good environmental policy should result in higher prices for pollution-producing goods, since this will signal the marketplace to reduce consumption of these products. The resulting burden for payment of charges, the second burden of the double burden, is in fact a payment reflecting the value of scarce air resources used for waste disposal.

Table 6.6.1.1

Annualized Control Costs Plus Charge Liabilities Under Three Alternative Charge Systems

	Annualized Control Costs Plus Charge Liabilities (Millions of Dollars)	Charge Liabilities (Million $)	Control Costs (Million $)
Optimal Charge	26.4	5.4	21
Source Category	169	75	94
Uniform	707	468	239

Three conclusions emerge immediately from this comparison. First, in terms of total costs to emissions sources, an optimal charge system (i.e., one based on source-specific charge rates) imposes by far the smallest burden on sources (and ultimately on society). The optimal charge results in estimated costs plus charge payments that are but a fraction of those associated with the other two alternatives considered. Second, under an optimal charge system, the "double burden" of charge payments is small in relation to control costs, amounting to only about 25 percent of control costs. The same certainly cannot be said of the other alternatives shown in Table 6.6.1.1, with charge payments amounting respectively to 80 percent and 196 percent of control costs. Third, the optimal charge results in a lower total cost to most sources than do either of the strategies examined in Chapter 5, which represent what might be achieved if a regulatory approach were adopted.

On the basis of total costs and charge payments for the AQCR, then, it is clear that the optimal charge system we have outlined in Section 6.2 above best meets some of the objections that have been raised against charge systems.

Another point concerning totals data for the three charge alternatives we have investigated is that the number of sources that incur positive costs is much smaller under the optimal charge system than it is under either of the other charge systems we have investigated, or under the regulatory baseline. It is quite possible that, confronted with this fact, assuming "one source, one vote," the so-called "optimal charge system" would be adopted in a referendum on the alternatives.

The real potential distributional difficulty with the optimal charge, as compared with the other charge systems we have examined and with regulatory approaches, is that it treats seemingly similar sources differently. That is, while very few sources are worse-off in absolute terms under the optimal charge system than under the other systems we have examined, some sources undeniably will be burdened in relation to other sources under an optimal charges system.

The statistical analysis presented in Section 6.5.2 indicates that these differences in burden may be explainable in terms of real, identifiable differences in sources' characteristics. This means that it can be argued that the optimal system treats like sources alike, and thus does not impose unequal burdens on like sources.

6.6.2 Options for Dealing with Distributional Considerations

If distributional obstacles are seen as a barrier to implementation of an efficient emissions charge approach, there are a variety of design options that could be pursued which preserve most of the efficiency properties of a charge approach while meeting distributional obstacles. We shall discuss two here to illustrate how distributional considerations can be incorporated directly into a charge design.

The first option that we will discuss is designed to deal with the double-burden argument. While we have argued that annual charge liabilities would not be very large under an optimal or near-optimal charge system, there are ways to shrink them still further while preserving most of the efficiency properties of the optimal system. A very straightforward modification of the optimal charge which reduces charge liabilities is to split the charge into two parts. The first part would apply to emissions below some cutoff quantity, and would be relatively low or even zero; the second part would apply to any emissions above the cutoff quantity and would be relatively high. [1]

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[1] The 1977 Clean Air Act Amendments in fact provide for something like a two-part charge. In particular, Section 120 prescribes a noncompliance penalty, designed to make sure that it is in sources' economic interest to comply with applicable regulations. A noncompliance penalty is similar in form to a two-part charge in that it is zero if a source is in compliance, and equal to the marginal cost of control if it is not in compliance.

To illustrate the effect of a two-part version of the optimal charge system on annual charge liabilities, consider a two-part charge system in which the first part charge rate is equal to marginal operating and maintenance costs, and the second part of the charge rate is equal to marginal total control costs. The level at which these costs are calculated, and the cutoff between the two parts, is the level of emissions (source-by-source) calculated by the mathematical programming model as described in Chapter 5 for the least cost emissions control strategy.

According to our calculations using Chicago data, a two-part charge system fashioned as described above would yield charge revenues of approximately $2.5 million, or slightly less than half the level yielded by the one-part optimal charge system. As noted above, revenues could be reduced further still by further reductions of the first part of the charge rate. Indeed, annual charge liabilities could be made approximately zero simply by setting the first part of the charge rate at zero.

It should be noted that any of the charge systems we have examined in the preceding sections of this chapter could be modified to two-part systems. In each case, the effect would be the same: annual charge liabilities could be significantly reduced.

There are legitimate arguments that can be made both for and against two-part (or multipart) charge systems. One argument in favor of the system is that the sharp step in the charge rate at a specified emissions level clearly shows emissions sources the level of control that the charge system is designed to attain. One need not perform any particularly sophisticated balancing of control costs with charge rates. Arguments against multipart systems are that they are more difficult to justify (not only must the charge rate structure be explained, but one must also explain the break points at which the various parts of the charge become effective) and that they fail to preserve the correct long-run entry and exit incentive properties of a one-part charge.

A second option which illustrates how a system can be designed to meet distributional objections while at the same time encouraging efficient attainment of ambient standards is to use the charge system to raise funds to finance abatement. This could be done, for example, as follows: First, a per pound per hour charge (equal across all sources) could be levied on all sources in the region, with the charge rate set at a level sufficient to yield revenues equal to the cost of the least cost emission control strategy. [1] Second, revenues collected could be used by the collecting authority to contract for (i.e., subsidize) the levels of abatement indicated by the least cost control strategy. An argument in favor of this approach is that it eliminates the need to justify a classification system for charge rates. It also, through the procurement process gives pollution control agencies direct control over the performance of sources which contract to reduce emissions. Arguments against the approach are that this charge structure distorts entry and exit incentives, and given agency uncertainty about sources' control options, could involve cumbersome and expensive contracting procedures.

The two design options discussed above illustrate the fact that distributional issues can be disentangled, at least partially, from efficiency issues and dealt with separately. If distributional considerations pose a barrier to adoption of a relatively simple efficient charge system, like the optimal charge system, these and other options should be pursued. There are immense gains from doing so, as is demonstrated by the large differentials between the costs of efficient emissions control strategies and inefficient ones.

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[1] With the charge based on emissions, it is implicitly assumed that the damage or impact from emissions is the same for all sources in the region.

6.7 Technological Considerations

We argued in Chapter 3 that one of the most compelling arguments in favor of a charge system is that it provides a continuous incentive to look for more efficient emission control technologies. Our quantitative analysis in Chapter 5 showed that this is a very important practical consideration. In order to meet a one hour standard of 250 $\mu g/m^3$, many sources will have to adopt emission control technologies that are not currently available, and are only projected to become available sometime between 1981 and 1985. The clear and unambiguous incentive provided by an emissions charge to develop new emission control technology is thus an important argument in their favor.

The different charge systems we have discussed in the preceding sections of this chapter each provide different levels of incentive to development of emission control technology. In general, the higher the sum of annual control costs and the annual charge liability, the greater the incentive. Thus, the Source Category and Uniform Charge systems discussed in Section 6.5 above provide greater incentives to emission control technology development than does the Optimal charge system. Similarly, one-part charge systems provide a greater incentive to development of new emissions control technology than do two-part incentives of the type discussed in Section 6.6.2 above.

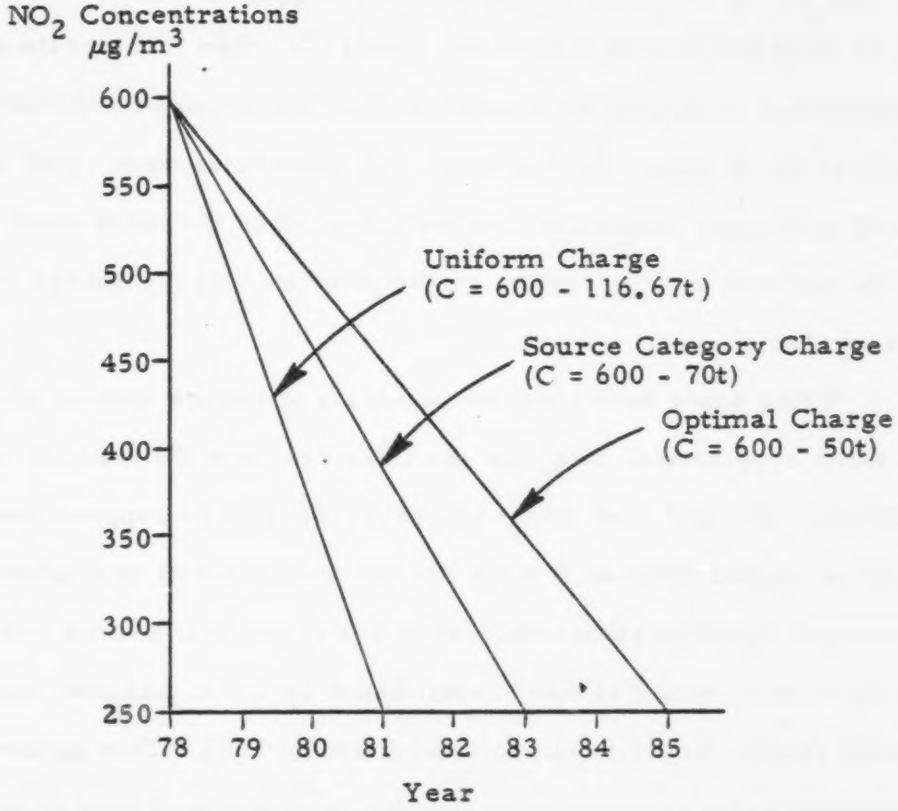
The rankings of the alternative charges we have examined thus differ, depending upon whether we compare them on the basis of their performance in meeting standards at least cost or on the basis of their performance in inducing development of emission control technology. The systems which meet standards at higher cost will provide a greater impetus to the development of more efficient emissions control technology. They will do so, however, at a relatively high cost. If our objective were to meet and maintain ambient standards, then these costs are excessive and technological considerations would not be sufficient justification to incur them. If, however, our objectives were rapid development of emissions limitations technologies, then the extra costs associated with the uniform charge system or the source category charge system may be warranted.

Using some data from our analysis of charge system alternatives and some hypothetical data, we can illustrate how the tradeoff between attainment date and cost might be analyzed. Let us suppose that adoption of our so-called Optimal Charge System would result in attainment of the short-term ambient standard level in 1985, that our Source Category Charge System would result in attainment by 1983, and that our Uniform Charge system would result in attainment by 1981. This pattern of attainment dates is purely hypothetical, and is meant only to reflect the conclusion which we reached above that charge systems which result in relatively high costs to sources provide relatively great incentives to technology development.

Let us further assume that the pattern of progress is such under each of the three alternative charge systems that the second highest hourly concentration declines linearly from its present level of approximately 600 $\mu g/m^3$ to 250 $\mu g/m^3$ in the attainment year. This hypothetical pattern of progress is depicted below in Figure 6.7.1. The equations for each line are given in parentheses, with t = 0 in 1978.

Figure 6.7.1

Hypothetical Progress Paths Under Three Alternative Charge Systems



Using these assumptions, and the approximate value of reducing a maximum short-term ambient concentrations of $80,000 per year per microgram per cubic meter derived in Chapter 5 (see Section 5.5), we can compute the implied benefits of accelerating attainment of the ambient standard. Taking the progress pattern which results in attainment by

1985 as the baseline, the incremental benefit of accelerating attainment from 1985 to 1983 may be calculated approximately as

$$(600 - 50t) \times \$80{,}000 - (600 - 70t) \times \$80{,}000$$

or

$$\$1{,}600{,}000t$$

Using a discount factor of 10 percent, the implied present value (in 1973) of benefits of a 1983 attainment date instead of a 1985 attainment date is approximately $20.4 million.

When exactly the same calculations are made in comparing attainment in 1981 as opposed to attainment in 1985, we find annual benefits of approximately $5,333,600t (i.e., $(600 - 116.67t) \times \$80{,}000 - (600 - 50t) \times \$80{,}000$). The present value of benefits of a 1981 attainment date instead of a 1985 attainment date is approximately $68.1 million.

To be balanced against benefits of possible earlier attainment of ambient standards are the excess costs associated with the Uniform or Source Category Charge systems. For illustrative purposes, we will approximate these costs by the estimated excess control costs associated with the Uniform and Source Category charge systems. [1] We shall assume in our calculations that annual control costs grow linearly as depicted in Figure 6.7.2. The equations in parentheses give the equations for each of these lines.

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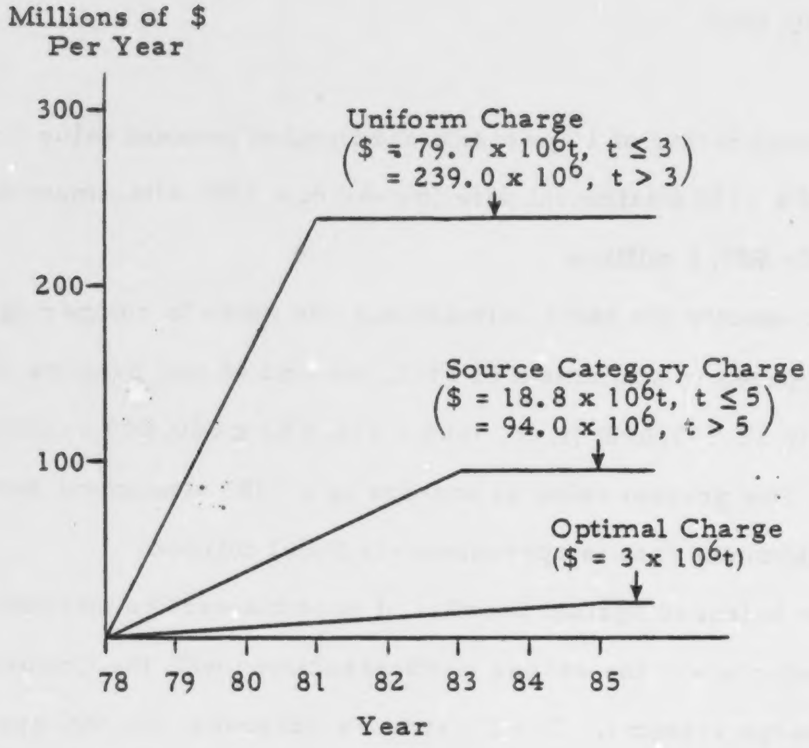
[1] We do not include excess charge payments in our calculations because these are not social costs, but rather are transfer payments.

Figure 6.7.2

Hypothetical Paths of Annual Control Costs

Under Three Alternative Charge Systems



The present value in 1978 of the extra costs of attaining standards in 1983 as opposed to 1985 has been calculated from the data shown in Figure 6.7.2, and amount to approximately \$226.1 million. A corresponding comparison of the hypothetical annual cost streams for 1981 attainment versus 1985 attainment shows a present value of costs of approximately \$818.3 million.

Both of these estimated cost figures (i.e., \$226.1 million and \$818.3 million) are very large in relation to the corresponding benefits estimates we have obtained (i.e., \$20.4 million and \$68.1 million, respectively). If these were actual data, we would conclude that the accelerated attainment of ambient standards that could be achieved through adoption of the Uniform or Source Category charge systems we have discussed would not be warranted on cost-benefit grounds.

6.8 Source Administration and Monitoring Costs

Under any policy approach to pollution control, sources bear the burden of some costs of monitoring and reporting upon their emissions. We would thus suppose that the costs associated with these activities would not differ very much as between a regulatory approach and one based upon an emission charge. Under both, sources would be responsible for measuring their emissions and reporting the results of these measurements to the appropriate pollution control agency.

In Chapter 2, we reported data concerning the state and cost of technology for continuous monitoring of NO_x emissions. Our general conclusion was that technically adequate emissions monitoring technology is available currently, at a cost that is small generally in relation to the cost of emission controls that will be required to meet a short-term ambient standard of $250 \mu g/m^3$. For example, the average annual cost of control per controlled source under a least cost emissions control strategy is approximately \$220,000. Under the assumption that each controlled source would require a separate monitoring system (this is clearly extreme since sources many times are co-located and could share at least some parts of a system), annual monitoring costs would probably average $25,000 per year per source, or about 11 percent of annual control costs.

The main difference between the administrative and monitoring activities that sources would have to conduct under a charge system as opposed to a regulatory system is that some additional accounting and recordkeeping functions would have to be performed. We have examined some alternatives for performing these functions and have found that they could easily and cheaply be integrated into the hardware and software of the emissions monitoring system. The paragraphs below illustrate how this could be done and approximately what it would add to the cost. The estimated increment in annual cost over a system which does not incorporate these additional functions is on the order of, at most, $2,500.

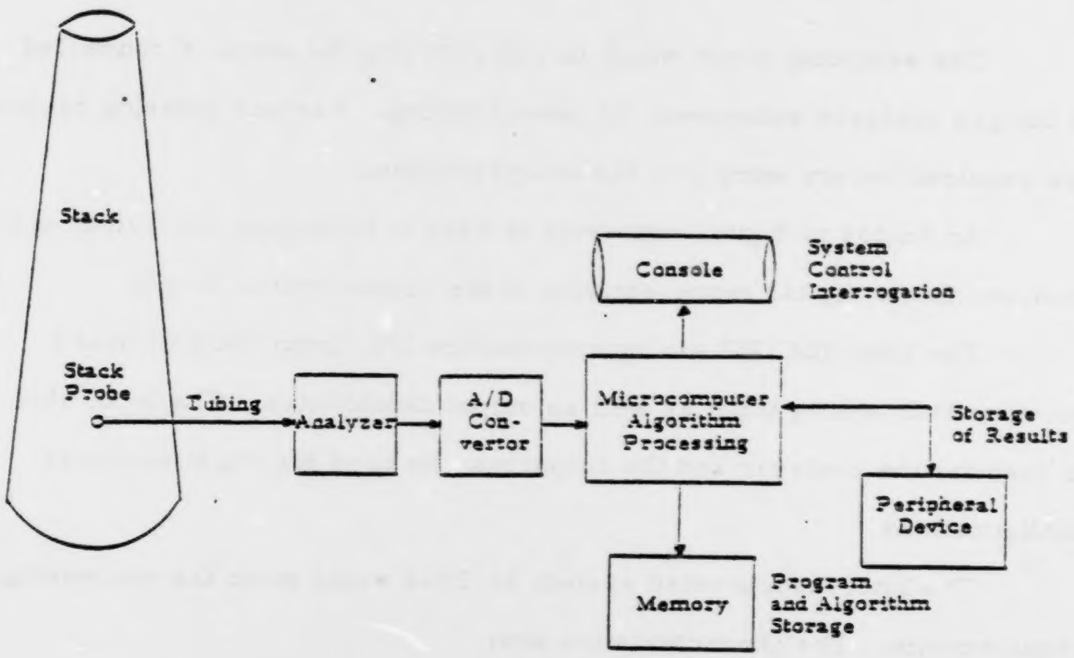
6.8.1 System Configurations

The system is to sample a continuous reading gas analyzer in real time at a frequency of 60 per hour. The analog output of the analyzer is converted into a digital value and processed and stored for reporting purposes. The processing algorithms require that charges be assessed based on the highest measured hourly emission rate. The period can be up to three months, and the processor is to be made rugged against the elements and as secure as possible against tampering.

Figure 6.8.1.1 shows a generalized diagram of the stack monitoring system. The analyzer provides an analog signal proportional to the concentration (ppm) of NO/NO_x. The signal is converted to a digital representation and is sampled each minute by the micro computer. Programs and

Figure 6.8.1.1

Microcomputer Based Stack Analyzer System


Stack
Stack Probe
Tubing
Analyzer
A/D Convertor
Microcomputer Algorithm Processing
Console
System Control Interrogation
Storage of Results
Peripheral Device
Memory
Program and Algorithm Storage

algorithms for determining charges are stored in non-destructible memory. Calculation results are output to a peripheral device for long-term storage and may be accessible for visual display on the system console.

The system is composed of major subsystems as follows:

- Stack Probe and Interface Tubing
- NO/NO_x Analyzer
- A/D (Analog to Digital) Converter
- Microcomputer
- Peripherals.

The sampling probe which is inserted into the stack is connected to the gas analyzer subsystem via heated tubing. Various filtering devices are required before entry into the analyzer input.

An analog to digital converter is used to transform the output of the analyzer into a digital representation of the concentration levels.

The Intel SBC 732 analog combination I/O (Input/Output) board provides both analog input as well as output capabilities. The input side is used for the analyzer and the output may be used for chart recorder configurations.

The Intel Incorporated system 80/20-4 would meet the processing requirements. The characteristics are:

- 4K bytes of RAM (Random Access Memory)
- 4K to 8K bytes of ROM (Read Only Memory)
- 1 Serial I/O Port (RS232C)
- 48 Parallel I/O Ports

The ROM will be used to store the system software and peripheral drivers. The RAM will be used to scratch the intermediate memory.

The following peripherals would be used:

- CRT display,
- Tape cassette, and/or
- Chart recorder.

A CRT display can be used to visually display the current pollution and cost assessment information.

A tape cassette can be used to store data for purposes of off-line processing to determine indebtedness for charge payments. The tape cassette could be submitted with payment as a means of cross-checking costs on a statistical sample basis.

As an alternative to the tape cassette, a long-term chart recorder has been proposed such that the analog of pollution is plotted. The associated charge assessment could be printed directly on the chart.

The Intel system provides an interface capability for a CRT display but not for a tape cassette. This would require some customized hardware and software which has been accomplished by Beckman Instruments. A chart recorder could be interfaced to the minicomputer but the interface characteristics would need to be specified once a vendor were chosen (e.g., Honeywell). What is envisioned is a three month circular chart but Beckman only supplies a one month strip recorder.

The processing requirements are to determine the charge payment based on the charge rate which applies to the source and the measured emissions. For example, the charge algorithm under a two-part charge might be as follows:

Given:

R = rated capacity of boiler in 10^6 Btu/hour

A, B, C, D = factors for coal fired utility boilers

M = maximum measured hourly emissions in a 24 hour period

C_A, C_B = cost factors

Algorithm:

$M = A \times R \times B$ Then $C_A = M \times D$

$M = A \times R \times B$ Then $C_A = (A \times R \times B) \times D$

and

$$T \times C = C_B$$

Then the total cost assessment is:

$$C_A + C_B$$

Figure 6.8.1.2 shows the data collection portion of the system software flow diagram and Figure 6.8.1.3 shows the charge calculation for a hypothetical two-part charge.

The storage estimates are as follows:

RMX/80 Real-Time Execution	2K bytes	ROM
Application Programs	1K-2K bytes	ROM
Tables and Buffers	1K bytes	ROM

System timing is considered to be an area not warranting concern. The process is essentially serial with a one minute periodicity so that data rates and multiprogramming requirements are minimal. The most complex period of operation would occur when interactive CRT interrogation of the system occurred. CRT interaction would require the operator to sign-on in order to obtain the current charge assessment information.

Figure 6.8.1.2

Data Collection

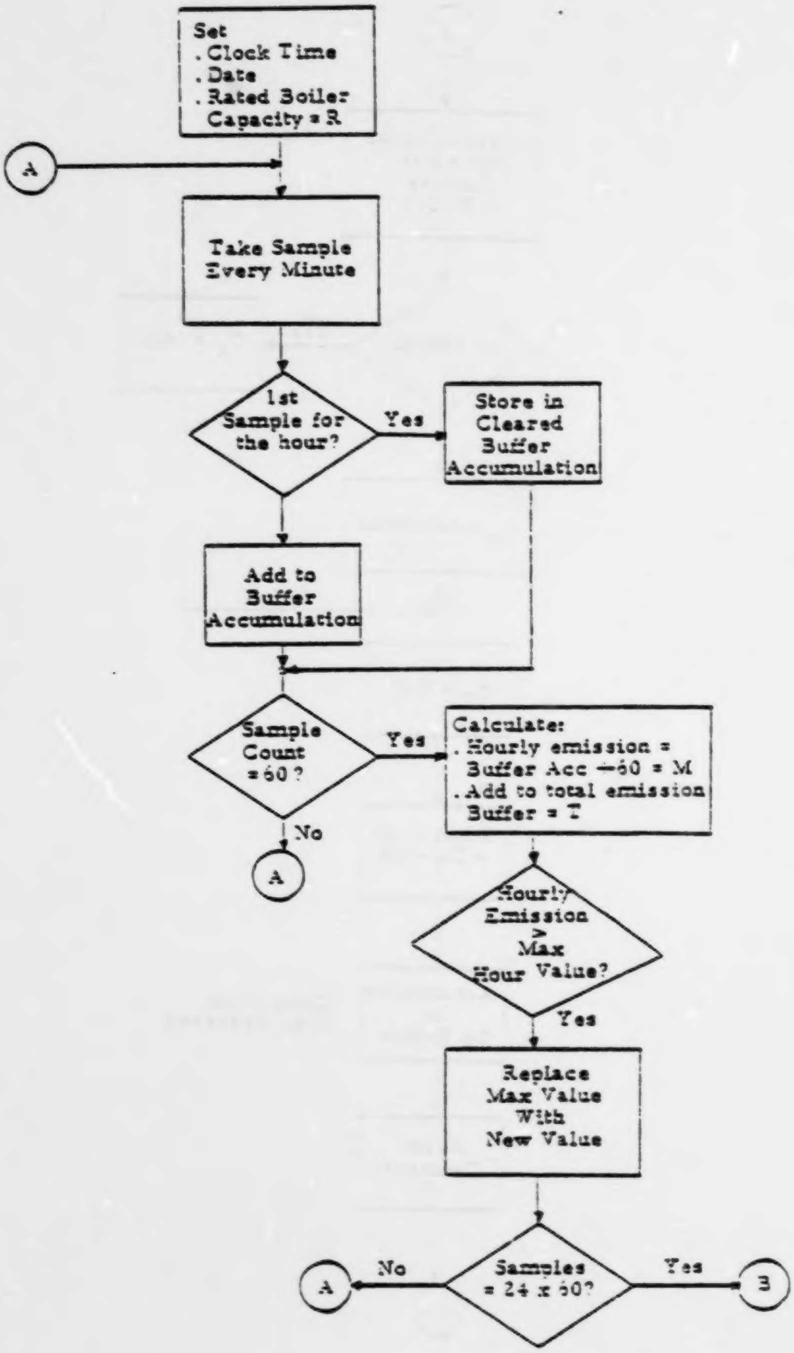
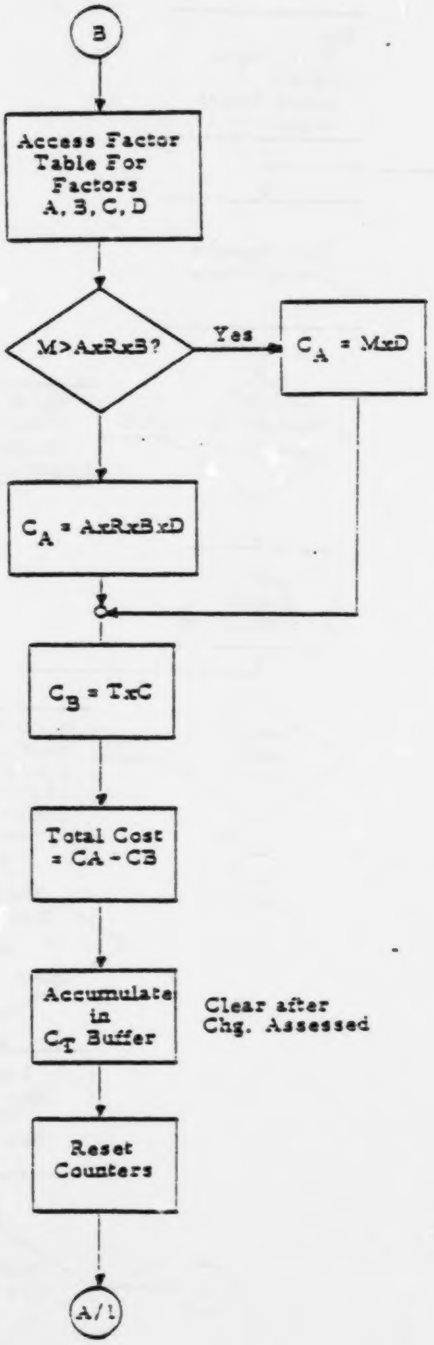

Set
. Clock Time
. Date
. Rated Boiler Capacity = R
A
Take Sample Every Minute
1st Sample for the hour?
Yes
Store in Cleared Buffer Accumulation
Add to Buffer Accumulation
Sample Count = 60 ?
Yes
No
A
Calculate:
. Hourly emission = Buffer Acc ÷ 60 = M
. Add to total emission Buffer = T
Hourly Emission > Max Hour Value?
Yes
Replace Max Value With New Value
No
A
Samples = 24 x 60?
Yes
B

Figure 6.8.1.3

Charge Calculation


B
Access Factor Table For Factors A, B, C, D
M>AxRxB?
Yes
C_A = MxD
C_A = AxRxBxD
C_B = TxC
Total Cost = CA - CB
Accumulate in C_T Buffer
Clear after Chg. Assessed
Reset Counters
A/1

The peripheral complement required for the application should be as tamper-proof as is possible. None of the choices is completely fool-proof.

The most secure environment that provides the user with the easiest means for charge determination is accomplished by using all three devices. However, any complement that uses at least two of the devices will provide a reasonable level of security for each of charge determination. The most tamper-proof complement is tape and chart. As a compromise solution, the console and chart are recommended. The chart is mailed to the control agency along with a check for assessed charges. The console is available for use by control agency inspectors to spot check chart calibration.

6.8.2 Estimated Development and System Costs

Software development can be accomplished using one of two available methods. The system 80/20-4 for field installation can be programmed directly in machine language or a development system MDS230 can be used as a higher level language (FORTRAN) development tool.

The system 80/20-4 cannot be programmed directly while using RMX/80 real-time operating system so that a custom operating system would also need to be programmed. The development system is more flexible and easy to program as it allows FORTRAN application code to be installed under RMX/80. For ease of development, it appears that the MDS230 is desirable. An estimated cost breakdown is shown below in Figure 6.8.2.1.

Figure 6.8.2.1

Estimated Cost Breakdown

Costs

1.	MDS230 Development System	
	Basic System	$13,950
	Fortran	$1,750
	On-Line Edit	NC
	RMX/80	$1,950
option	ICE-80 [1]	$2,500
2.	System 80/20-4	
	Basic System	$1,725
	A/D Converter SBC732 [2]	$1,125
	CRT/KB MDS CRT	$2,240
	ROM B2708-1	$106
	Misc (cables, etc.)	$500

Total Costs

Development System	$17,650 - $20,150 (ICE-80 optional)
Application System	$5,466 - $5,696 (A/D Converter option)

Estimated SW Development Costs

Design	2 weeks	$4,000
Implementation	4 weeks	$5,000

Total One-Time Charges

$17,650 - $20,150	Development System
9,000	SW Development
$26,650 - $29,150	

Unit System Charges

$ 5,466 - $ 5,696 Hardware

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[1] The ICE-80 option is useful for debug purposes as it essentially inserts the development system into the 80/20-4 to demonstrate program correctness.

[2] If a chart recorder is not used, the analog input device Model SBC711 can be used at $895.

6.9 Setting and Adjusting Charge Rates

It is clear from our discussion of charge systems in the preceding sections of this chapter and in Chapter 3 that in order to set and adjust charge rates a charge-administering agency must know sources' emissions rates and the relationships between control costs and emission rates if it is to devise charges that will be effective in eliciting the emission reductions required to implement a least-cost strategy.

It has been shown in the theoretical literature that the environmental authority could achieve its air quality objectives at least cost under a standards-and-charges program without knowledge of the polluters' control cost functions, [1/] by simply adjusting charge rates until the desired solution is achieved. In practice, however, the rigidities imposed by economic, political, and legal constraints make it difficult to place much faith in this as a viable alternative. We conclude that in order for an economic incentive approach to be fully implementable, the environmental authority must be able to approximate the polluters' control costs as a function of emissions.

In this section we analyze alternatives for obtaining such control cost information from pollution sources. Our criteria for comparing alternative sources of cost information are their cost and their effect on the cost of NO_x pollution control. Clearly, bad cost data may lead to bad decisions which will result either in unnecessary cost or in failure to meet and maintain ambient standards.

[1/] Baumol and Oates (1975), p. 144.

6.9.1 Two Sources of Cost Information

Two possible sources of information on polluters' cost-of-control functions have been considered. We shall refer to these as "engineering studies" and "bid".

6.9.1.1 Engineering Studies

As discussed in Chapter 2, current regulations require new polluters to install the Best Available Control Technology (BACT) in areas that have attained acceptable air quality, while existing polluters install Reasonably Available Control Technology (RACT) or new polluters install Lowest Achievable Emission Reduction (LAER) in areas where nonattainment is a problem. 1/ These concepts are essentially technology-based standards. As such, they rely on engineering studies to provide information on pollution control technologies and costs. 2/ The rationale behind these studies is basically one of data development on the costs and effectiveness of alternative technological processes designed to reduce emissions.

Engineering studies are commonly used today for obtaining the necessary information to meet the mandates of air quality legislation. These studies develop estimates of the costs and degree of emissions reductions achieved by the application of selected control technologies (or a combination of control technologies) to example plants.

1/ See Chapter 2, Section 2.3.1.

2/ Note, however, that LAER is not concerned directly with costs. Instead, it focuses on the technical feasibility of the control technique.

6.9.1.2 Bid

A second technique for obtaining control cost information to generate cost curves as a function of emission reductions is the bid approach. Under this alternative, each source would report its estimated cost of control for each of several levels of emissions reductions.

Under the bid approach, estimated costs may reflect consideration of more emissions control options than would be reflected in engineering study estimates. That is, instead of focusing only on control technologies, the polluter is more likely to include other methods of controlling emissions (for example, changing input or output mix, altering the production process). The main implication of this difference is that, all other things being equal, one would expect the bid approach in the absence of biased reporting to yield lower and more nearly correct estimates of cost.

6.9.2 Costs of Alternative Approaches

There are, as noted above, two kinds of costs that are affected by the choice between alternatives for obtaining control cost information. These are (1) the costs associated with obtaining cost data, and (2) the costs associated with erroneous decisions that could flow from erroneous data.

Although we have no hard data on the subject, it seems probable that the cost of obtaining cost data via engineering studies would be much smaller than doing so via a bid approach. As noted above, engineering cost studies are conducted on a continuing basis by the U.S. Environmental Protection Agency to meet its responsibilities to conduct research and development on control technologies, to report to the nation on the cost of air pollution control, and for standards development. Therefore, the incremental cost of the engineering approach, assuming that this engineering cost information developed for other purposes could be shared, would be just about zero.

In contrast, the bid approach potentially could involve a substantial effort on the part of both sources and the control authority. Sources may, for example, choose to perform their own special feasibility studies prior to submitting estimated cost data. The control agency must provide a means to process and store cost data submitted on a source-by-source basis. 1/ We have no basis for estimating what the magnitude of these costs might be but speculate that for the Chicago AQCR they might run to as much as $1 million per year.

The cost of erroneous decisions, in contrast to the cost of obtaining cost information discussed above, could be quite substantial. Both kinds of cost data -- engineering costs and "bid" costs -- are subject to error. In the case of engineering cost data, cost estimates are based upon model plants and thus reflect an average. For some plants, the estimates may be too high, and for others too low. A second source of error in engineering cost estimates which we noted above is that they are based upon consideration only of selected emissions limitation options. Since sources may in fact have more options (e.g., process changes, changes in operating parameters), engineering estimates thus may tend to be higher than costs actually incurred, other things being equal.

1/ Some experience of this kind has been gained by control agencies through the implementation of the non-compliance penalty section of the Clean Air Act (Section 120). This past experience could help reduce some of the resource costs associated with starting up and maintaining the data processing effort required.

Data obtained by the bidding approach described above is also subject to error. While it seems reasonable to believe that estimates obtained via the bid approach would be less subject to error due to lack of consideration of source-specific characteristics or to the biases that arise when only a limited range of options is considered, error undoubtedly still would remain. In addition, since sources would recognize that bids would influence charge-setting decisions, they may (depending upon the way in which bids are solicited) have incentives to deliberately misstate their costs of control.

We can only speculate as to the magnitude of costs associated with the errors described above. The evidence we have examined in other sections (see Section 6.5) shows that systematic departures from an Optimal Charge rate can be extremely costly. It seems reasonable to conclude that accidental departures due to erroneous information could be very costly too.

The potential for error, systematic and random in cost information obtained by whatever means presents one of the most difficult problems that may be faced in design of a workable charge system. The problems are particularly acute under a system like our Optimal Charge system, where individual charge rates are based in part upon individual cost of control relationships. In a nutshell, the problem is this: if engineering data are used, engineering estimates may be erroneous (perhaps by a very wide margin). This means, as we have demonstrated amply above, that excess costs would be incurred. If sources' cost estimates are used, data may still be erroneous, perhaps randomly and perhaps systematically, and the charge setting authority is faced with the prospect of having to evaluate and decide upon the appropriateness of source reported cost estimates. This could pose a huge administrative burden to the charge setting process, with uncertain results concerning the quality of the estimated costs that would be obtained.

There is, in our opinion, no demonstrably "best" (or even "good") solution to this problem. A seemingly sensible and workable solution, however, is the following. Engineering estimates would be used as default values for purposes of setting charges. These values would be available for public inspection prior to the setting of charges. Sources that wished to submit alternate estimates, prepared in accordance with a set of EPA-issued guidelines, would be permitted to do so. These alternate cost estimates would be subject to audit and approval by the charge-setting authority. Default values or approved alternative values would then be used as outlined in the preceding sections of this chapter to set charge levels.

6.9.3 Adjusting Charge Levels

All of the data on which charge levels are based according to the design laid out in the preceding sections of this chapter change with time. As we have discussed in Chapter 3, price levels change, emissions control technology changes, and the population of sources changes. Clearly, charge levels must be changed to reflect these changes if a charge policy is to be efficient and effective.

To make these changes, the charge-setting procedure outlined in Section 6.2 could be repeated every year, based upon updated information on control costs and source population. Recalculated charge rates would thus reflect relatively current data. The difficulty with this approach is that there is no guarantee that charge rate revisions would be small or predictable. It is quite possible that some (perhaps even most) rates could change by a substantial amount. This could be quite disruptive, and could pose a serious barrier to public acceptance of a charge policy.

An alternative (and we think preferable) procedure for adjusting charge levels would be to limit the percentage change which could occur in any year. For example, constraints might be imposed which would limit the adjustment in charge rates in any year to, say, 10 percent from year to year. Such a constraint could be incorporated directly into the mathematical programming procedure for computing charge rates. This procedure should reduce (although not eliminate) uncertainty concerning charge rates and public opposition to charge rate increases.

6.10 Administrative Considerations

Table 6.10.1 details the man-year and cost estimates for the range of agency administrative, monitoring, and enforcement activities that would be required to implement a charge system like the "Optimal Charge" system.[1] Note, there are effectively two stages to the manpower effort. In the first year of the program, the estimates of transfer coefficients, the appropriate standard for ambient air quality, background levels, growth allowances, and engineering-based emissions control cost curves would all need to be derived. Subsequent to this initial effort, there would be less intense, on-going efforts to "improve" these inputs; the major task once the program was operational would be devoted to activities associated with setting the optimal charge rate. The following discussion focuses on these recurring costs.

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[1] These costs and manpower figures cover federal, state, and local agency responsibilities. These estimates do not include overhead and fringe benefits.

Table 6.10.1

Manpower and Cost Estimates for Emissions Charge Program, City of Chicago (1978 Dollars)

A. Initial Effort	Man-Years	Cost
1. Dispersion Modeling	.24	$ 5,000
2. Air Quality Standard	.16	4,000
3. Engineering Based Control Cost Curves	.32	6,000
4. Equipment Expenditures	---	150,000
Total	.72	$165,000

B. Recurring Administrative, Monitoring, and Enforcement Activities	Man-Years	Cost
1. Administration	29-37	$370,000-489,000
2. Monitoring	8-15	108,000-207,000
3. Enforcement	19-44	280,000-631,000
Total	56-96	$758,000-1,327,000
Total First Year		$923,000-1,492,000
Recurring Total		$758,000-1,327,000

The manner in which the various manpower and cost estimates were derived was taken from the methodology employed by Lynn and Deane.[1] The format of their model presumes three major divisions of agency responsibility. These include: (1) activities projected from source information (enforcement practices); (2) activities projected from monitoring system information; and (3) activities projected from management-related responsibilities. The types of specific activities we associated with each of these divisions for the emissions charge program are given below.

The enforcement activities include:

- Determination of Emissions Control Cost Curves for Individual Sources
- Establishment of the Charge Rate from Solution to Mathematical Programming Problem
- Stack Testing
- Observations of Stack Tests
- Complaint Investigation
- Legal Action.

The monitoring activities pertain to field monitoring of ambient concentrations and involve the following tasks:

- Field Operation of Monitoring Equipment
- Calibration and Maintenance of Equipment

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[1] Lynn and Deane (1975). The Lynn and Deane model is defined for state and local staffing requirements. Federal manpower effort was estimated independently.

- Sample Preparation and Sample Analysis
- Data Handling
- Special Monitoring Studies
- Network Planning
- Travel Time
- Air Quality Data Analysis.

Finally, management activities cover:

- Program Management
- Strategy Development
- Liaison Activities
- Training
- Clerical Support.

Manpower estimates for these activities are also derived through procedures used by Lynn and Deane. For source-related activities they defined a matrix of source activities versus various source types. The monitoring-related activities are also represented by a matrix. This matrix, however, relates the monitoring activities to the types and number of sensor devices. Finally, estimates of manpower requirements for the management-related activities are based on the magnitude of staff employed to carry out the activities of the other two major divisions.

For source-related enforcement activities there are three characteristics that describe the relationship between source type and source activities. These factors can be identified as: (1) Manpower Coefficients; (2) Applicability Factors; and (3) Frequency Factors. 1/

1/ For convenience, we have incorporated the frequency factors into the applicability factors. All applicability percentages are expressed on an annual basis.

Tables 6.10.2 and 6.10.3 present the range of factors we used in deriving the manpower estimates shown in Table 6.10.1 for enforcement activities.

Given the manpower resource requirements, we used salary information in the Air Pollution Control Strategy Resource Estimator Model (APCSRE) in order to estimate costs. 1/ Annual salary levels for various job classifications are given in Table 6.10.4. Since these estimates are in 1976 dollars, we respecified them in 1978 dollar terms in order to maintain comparability with the cost of control figures derived in Chapter 5. We assume the pay scales of air pollution control agency personnel increased at a rate of 5 percent per year for each of 1977 and 1978. These increases are in accord with observations made in the APCSRE model on recent trends in wages in the area as well as with our own review of employment cost indices for professional and technical workers in the past two years.

The totals in Table 6.10.1 indicate that an emissions charge program for the control of NO_x emissions could be implemented in the Chicago AQCR for a first-year cost of about $1 million to $1.5 million with subsequent annual costs ranging from $750,000 to $1.3 million. For comparative purposes, we have also derived a range of AME cost estimates for a regulatory system. The basis for our calculations was once again the Lynn and Deane manpower planning model. Since their model considers

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1/ See Air Pollution Control Strategy Resource Estimator Model (1975), Table 3-7.

Table 6.10.2

Manpower Factors for Stationary Source Activities

Time (Hours) per Unit Performance per SCC - Emissions Charge Program

Source Type a/	Activities				
	Cost of Control Curves	Charge Rate	Stack Testing	Observe Test	Legal Action
1. Utility, Coal >10 MMBtu/hr. (21)	8-16	8-16	32-64	8-16	200
2. Utility, Oil & Gas >10 MMBtu/hr. (11)	8-16	8-16	32-48	8-16	200
3. Industrial Coal >100 MMBtu/hr. (60)	8-16	8-16	32-48	8-16	200
4. Industrial Coal 10-100 MMBtu/hr (37)	8-16	8-16	24-40	4-8	200
5. Industrial Oil & Gas >100 MMBtu/hr. (109)	4-8	8-16	24-40	4-8	200
6. Industrial Oil & Gas 10-100 MMBtu/hr (420)	4-8	8-16	20-32	4-8	200
7. Gas Turbines (11)	4-8	8-16	20-32	4-8	200
8. Industrial Processes (116)	4-8	8-16	16-32	4-8	200
9. Nitric Acid (8)	4-8	8-16	16-32	4-8	200
10. Municipal Incinerator (4)	2-4	8-16	16-24	2-4	200

a/ Numbers in parentheses are total number of sources in category

Table 6.10.3

Applicability Factors for Stationary Source Activities

Percentage of Sources Subject to Activity - Emissions Charge Program

Source Type a/	Activities				
	Cost of Control Curves	Charge Rate	Stack Testing	Observe Test	Legal Action
1. Utility, Coal >10 MMBtu/hr. (21)	100	100	100	200-300	3-7
2. Utility, Oil & Gas >10 MMBtu/hr. (11)	100	100	100	200-300	3-7
3. Industrial Coal >100 MMBtu/hr. (60)	100	100	100	200-300	3-7
4. Industrial Coal 10-100 MMBtu/hr (37)	100	100	100	200-300	3-7
5. Industrial Oil & Gas >100 MMBtu/hr. (109)	100	100	50-100	100-200	3-7
6. Industrial Oil & Gas 10-100 MMBtu/hr (420)	100	100	50-100	100-200	3-7
7. Gas Turbines (11)	100	100	50-100	100-200	3-7
8. Industrial Processes (116)	100	100	50-100	100-200	3-7
9. Nitric Acid (8)	100	100	50-100	100-200	3-7
10. Municipal Incinerator (4)	100	100	50-100	50-100	3-7

a/ Numbers in parentheses are total number of sources in category.

Table 6.10.4

Survey of Salary Levels at State and Local Air Pollution Control Agencies [a]

(Annual Salary, in Thousands of Dollars)

Occupational Category	High	Low	Overall Sample Mean
1. APC Director	32.11	15.60	23.24
2. APC Deputy Director	27.09	15.05	22.68
3. Legal Officer	22.95	6.00	15.67
4. APC Specialist II	22.64	12.00	17.36
5. APC Specialist I	24.47	8.05	13.78
6. Engineer II	29.87	11.86	18.65
7. Engineer I	22.24	8.78	15.42
8. Chemist II	18.52	8.39	14.72
9. Chemist I	15.22	6.96	11.91
10. Meteorologist II	18.06	12.00	13.15
11. Meteorologist I	13.10	9.66	11.44
12. Inspector III	18.15	10.15	13.59
13. Inspector II	18.77	7.40	12.83
14. Inspector I (Tr.)	9.77	8.76	9.25
15. Technician III	20.22	8.78	12.87
16. Technician II	15.20	7.60	11.30
17. Technician I	13.80	7.33	9.61
18. Aide II	12.00	7.32	8.98
19. Aide I	8.57	2.87	6.65
20. Clerical	16.05	5.15	7.82

Source: Abridged from Table 3-7, Methodology Report, Air Pollution Control Strategy Resource Estimator, vol. II, p. 40.

[a] Sample included all agencies in EPA Region V, Texas Air Control Board, and the San Diego Air Pollution Control District.

only state and local agencies, supplementary data were obtained on case development activities in order to account for federal involvement. [1] [2]

Meaningful comparisons of AME costs for different control strategies require a standard of reference. The air quality constraint of 250 $\mu g/m^3$ provides such a standard. That is, we want to make comparisons at a level of expenditure that is consistent with attainment and maintenance of the 250 $\mu g/m^3$ standard.

With the above considerations in mind, our estimated range for the regulatory AME costs is on the order of $900,000 to $2.6 million annually and involves 61 to 154 man-years of effort. The additional cost factor can be traced primarily to the expenditures necessary to negotiate and maintain acceptable compliance schedules, and when necessary to initiate legal proceedings. Thus, not only does an optimal charge program realize a large cost savings in terms of control costs relative to a regulatory system, but the contribution of AME costs to total social costs also appears to favor the charge system.

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[1] The derivation of our regulatory manpower estimates was aided through conversations and correspondence with: Tom Donaldson, USEPA, Control Program Section, Research Triangle Park; Ron Shafer, USEPA, Washington, D.C.; Pat Reape, Enforcement Division, USEPA, Region V; Wayne Jones, Division of Air Pollution Control, Illinois EPA; and Mr. Kason of the Department of Environmental Control, City of Chicago.

[2] For an excellent description of the effort involved in negotiating and enforcing compliance schedules under a regulatory system, see Anderson, *et al.* (1977).

6.11 Conclusions

This has been a long chapter due to the many experiments with designs carried out and the necessity to discuss and analyze the results of each. Before continuing, with our discussion of policy designs for marketable emissions permits in Chapter 7, it may be useful to restate here the major conclusions which we believe may be drawn from our analysis.

First, our analysis clearly shows that charge designs which establish charges on a source-by-source basis, with individual charges related to individual source's contributions to ambient concentrations, can meet ambient standards at significantly lower cost than can charge systems that make only gross distinctions (if any) between sources. We conclude that actual charge designs should approximate the results of the ideal source-by-source charge as closely as possible. While we acknowledge that there are practical difficulties in implementing a system which seems to treat similar sources differently, we believe the savings from so doing provide sufficient potential inducement to all parties. Moreover, we are not at all certain that the relevant bodies politic are incapable of persuasion that the differences between charges inherent in a good design reflect differential use of scarce resources which should be charged for at different rates.

If, for whatever reason, it is necessary to consider charge designs that do not approximate the ideal, this does not mean that the economic case for a charges policy as an alternative to regulatory policy is weakened. A charges policy still retains the inherent advantages that it tends to be lower cost in the presence of uncertainty and that it tends to be more effective in inducing the development and adoption of new, more effective emissions control technology.

Our second major conclusion is that the incremental costs directly attributable to the administration of a charge system like that we have designed are likely to be of the same order of magnitude as the cost of implementing an effective regulatory policy for control of stationary source NO_x emissions. In absolute amount, we estimate the administrative costs of a charges policy to be slightly less than the costs of a regulatory policy. While our estimates of these costs are at best approximate, a comparison of their rough magnitude with the estimated magnitudes of control costs under different policies suggests that refinements would not change our conclusion that a charges policy is superior on the basis of cost-effectiveness to a regulatory policy.

Third, and finally, our analysis shows that an important practical difficulty in implementing an emissions charge policy that approximates the ideal will be obtaining accurate source-by-source cost information. While we do not minimize the difficulty of adequate diffusion analysis (which also is required to implement the design we have proposed), we think an analysis like that reported in Chapter 5 provides an adequate basis for computation of charges. We are much less satisfied with using engineering cost information for model plants (as we have in our analysis in this chapter) as a basis for setting charge levels. As we have pointed out, sources tend to be sui generis, with wide variations in control options and costs from source to source. We also pointed out that engineering costs of necessity consider only a limited number of the options that actually may be available to sources. We also noted that the phenomena of inflation and technical change require that cost estimates be constantly updated if they are to be a fair reflection of current conditions. While we propose some practical solutions to these problems, none in our opinion is likely to produce very accurate information. The agency will have the same difficulties in getting good cost information to set charges as it does in getting good cost information to set regulations. Although we know, based upon our analysis, that imperfections in the agency's cost information poses a less serious problem than it does under regulation (see Sections 3.5 and 4.3), the cost information "problem" should not be minimized. Better information would make possible a better incentive system design.

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CHAPTER 7

DESIGN OF A MARKETABLE EMISSIONS PERMIT POLICY FOR CONTROL OF STATIONARY SOURCE NO_x EMISSIONS

7.1 Introduction

In this chapter we investigate another economic policy alternative to current regulatory policy. The policy examined in this chapter is based upon marketable emissions permits. Under a marketable emissions permit policy pollution control agencies take a much different role than they do under a charges policy of the type discussed in the preceding chapter. In order to administer a charges policy, the agency must seek out information and make decisions about incentive levels. It is thus a very active player in the game. Under a marketable emissions policy, an agency's role may be likened to that of an umpire: it sets the rules and judges the play; it does not play itself.

Our analysis in this chapter will show that this feature of a marketable emissions charge policy makes it an attractive alternative relative to a policy based upon charges. It will also show that a marketable permits policy could be viewed as a simple reform of some regulatory policies currently in force. This also is a point in its favor since implementation of such a policy would occasion less disruption than would implementation of a less-familiar charges policy.

As in Chapter 6, most of our quantitative analyses in this chapter are based upon the simulation results reported in Chapter 5. Thus, the basic results we present include no analysis of the effects of uncertainty, of technical change and growth, of the possibility for time-of-day or seasonal permits, or of the effects of transactions costs (which we believe would be low) on the operation and relative performance of a marketable permit system. We believe, however, that consideration of these additional factors would not result in material changes in our qualitative conclusions.

We should also note that fewer design variations for permit systems are considered in this chapter than were considered for charge systems in the preceding chapters. There are two reasons for this. First, as noted above, all of our calculations of the quantitative effects of alternative design decisions are based on the simulation results reported in Chapter 5. Thus, exploration of alternative designs would simply repeat material (albeit in slightly -- but only very slightly -- disguised form) to be found in Chapter 6. For example, if we were to examine control costs under a permit system design that stipulated that only those categories of sources controlled in a least cost strategy need obtain permits, and that the price of permits to all sources in a given category be the same, a moment's reflection tells us that our estimates of costs and revenues would be exactly the same as those we have reported for the Source Category emissions charge in the preceding chapter.

There is, however, a second and more fundamental reason for narrowing the range of designs we examine. We know, on the basis of results reported in earlier chapters, that policy designs approximating the ideal potentially can result in substantial savings of society's scarce resources. These are the designs we want to encourage. And these are the designs we shall discuss in this chapter.

The plan of the chapter is as follows. In Section 7.2 we summarize a basic design for a permit system. As was the case for our design of a charges system, we have designed a system which requires computation of mathematical programs. Given the state of the computing arts and the growing use of computer capabilities in air pollution control, we do not view this as unreasonable. The basic plan outlined in Section 7.2 provides for a periodic government operated market in emissions permits.

Section 7.3 explores distributional considerations and ownership questions. Using the results of our Chicago case study and the theoretical results presented in Chapter 4 showing the connection between least cost strategies and incentive structures, we know that the prices for permits will tend to vary widely between sources. These differences will reflect differences in contributions to ambient concentrations. An important difference, however, is that the control agency does not set these prices in the same way that it sets charge rates. The prices result from simple impersonal application of a set of rules for matching orders to buy and sell. Moreover, the matching rules are arguably sensible.

Section 7.3 also briefly examines the question of permit ownership. While there undeniably are some advantages to be gained from private ownership, we recommend that a more flexible system would provide for government ownership of permits, with sources leasing permits from the government or re-leasing permits from other sources.

Section 7.4 analyzes the question of how frequently the market should operate. While we have insufficient data to come to a precise conclusion on this subject, our analysis shows that if there is substantial uncertainty (as there would be, for example, if emitters had no knowledge concerning bid and asked prices that would result in transactions) or variability in control costs (e.g., due to seasonal or cyclical factors), substantial amounts of money can be saved by operating the market frequently. Since we believe that uncertainty and variability are important, and that the costs of market operation are relatively low, we recommend daily operation.

Additional safeguards against uncertainty are discussed in Section 7.5. Recall that in Chapter 3 we noted that policies which fix the number of permits can result in intolerably high costs of control. To provide a safeguard against this, we show in Section 7.5 how a surcharge can be built into the system to protect against this possibility. We will also show that this safeguard helps to solve the problems of insuring that sources emit only what they are entitled to by virtue of permit units held except under exceptional circumstances.

Other safeguards against uncertainty explored in Section 7.5 are options and futures markets. Our analysis shows that these markets can be operated in the context of the system we propose at relatively little additional cost. In view of their advantages in reducing uncertainty about the future, we recommend that futures and options markets be incorporated into any marketable permit system design.

Section 7.6 touches briefly on legal and administrative considerations in design of a marketable permit system. We find no legal barriers to adoption of such a system.

In Section 7.7 we estimate the public costs of operating a permit system designed along the lines discussed in this chapter. Our analysis shows that these costs are quite small in relation to the costs of emission controls under the strategies we have examined, and that in any event they are small relative to the costs of administering a regulatory policy.

Section 7.8 briefly summarizes our conclusions in this chapter. Our main conclusions are these: First, a marketable permit system provides an efficient and effective policy instrument for implementing pollution abatement. This policy tool is most efficient if it is designed to take into account differences between sources' contributions to ambient concentrations. Second, the costs of implementing a marketable permit system are likely to be of the same order of magnitude as the costs of implementing an effective regulatory policy for the control of stationary source NO_x emissions, and perhaps slightly less in amount. Therefore, we do not believe that these costs (i.e., the costs of administering policy) would alter our basic conclusion that a marketable permits policy is a more efficient policy than a regulatory policy to implement pollution abatement. Third, an important advantage of a marketable permits policy relative to both regulatory policies and emissions charge policies is that the agency needs to take less initiative in acquiring information needed to set policy parameters. Instead, the information is revealed during the impersonal workings of the permit market. Fourth, another important advantage of a marketable permits policy relative to both regulatory policies and emissions charges policies is that the marketable permit policy provides a natural way for sources to insure against uncertainty. In particular, this could be done through options and futures markets in permits.

7.2 A Basic Permit System

7.2.1 Permit Units

While the "results" of a marketable permit system are intended to be the same as those of an emissions charge system (i.e., efficient and effective pollution control), the basic design of the two policy instruments is very different. Under a charge system, a set of "prices" on emissions is calculated and levied by a pollution control agency. Under a marketable permit system, permits are issued by an agency. Once issued, however, their value and the allocation of them between sources are determined basically by exchanges initiated by sources. The role of the agency under such systems is thus a relatively limited one. It must decide what activities permits are required for, how many permits to issue, and what constraints to impose upon exchanges. It need not take the initiative to obtain accurate information on individual sources' control costs or process this information to calculate charge rates, or adjust charge rates to reflect new cost information or growth of emissions as it would have to do under a charge system. 1/

The basic decisions to be made in setting up a permit system are (1) the units in which permits are to be denominated, (2) the number of permits to be issued, and (3) the rules that will govern exchanges.

As discussed in Chapter 6, the most sensible choice of units on both cost and effectiveness grounds appears to be emissions. Moreover,

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1/ The agency would, of course, still require the more general cost information needed to (say) estimate economic effects of standards.

since we must control peak emissions in order to reduce short-term concentrations, our permit units must be denominated in terms of emission rates. [1]

7.2.2 Number of Permits

There are two main considerations which bear on the choice of the number of permits to issue. First, there is no simple relationship between the number of permits and ambient concentrations. The concentrations that would result from the exercise of any given number of permit units depend upon the circumstances under which permit units are used, including the locations at which all units are exercised and the relevant factors affecting dispersion of pollutants once emitted. Second, it may be that, given existing technology, emissions cannot be reduced to the number of permit units which could be issued and still attain ambient standards. Indeed, we saw in our simulation study of Chicago reported in Chapter 5 that sources will have to reduce emissions rates to levels that cannot, given current technology, be attained. We shall address each of these problems below.

It is clear, given our objectives of economy and effectiveness, that any sensible choice of the number of permits issued must take account both of the value of permits to society and the effect of exercise of permits on the environment. The easiest way to do this is to establish a pseudo-market institution designed to find the number and allocation of permits that maximizes the value that society gets from using its scarce air resource while assuring that such usage is consistent with attainment and maintenance of ambient standards. [1/]

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[1] Thus a permit unit might be denominated as "one pound per hour of NO_x emissions."

A variety of ways have been proposed to do this. One way that has been proposed, for example, is to simply issue permit units to all sources, with the number of units issued proportional to baseline emissions. The constant proportionality would be determined by the crude rollback percentage estimated to be required to reduce emissions to levels required to meet ambient standards. Sources would then be free to exchange permit units subject to any checks that might be imposed to insure that exchanges did not result in violations of ambient standards.

This way of determining the number of permit units to be issued is very crude, and for that reason, more costly than strictly necessary. Our quantitative analysis in Chapter 5 shows that if the rollback method were used to determine the number of permit units to issue, the number of units issued would be approximately 100,000 permit units less (recall that one permit unit equals one pound per hour NO_x emissions) than would be issued under an ideal permit system designed to implement the least cost emission control strategy.

To more nearly approximate a permit system which would issue the optimal number of permits and provide for their exchange subject to ambient constraints, we propose the following system. The agency would first distribute a pro rata number of permits to each source based (for

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[1/] Strictly speaking, the goal of a permit system should be to allocate permits in such a way as to maximize the "surplus" value (i.e., willingness-to-pay for permits) of permits, subject to attainment of the ambient standard. For a more precise formulation, see the discussion in Section 4.3 on permit systems.

example) on prior years' emissions. Then, the agency would offer an indeterminate additional number of permit units, the number finally to be determined by sources' bids for permits and diffusion analysis. Buying and selling would take place via a periodic market in which offers to sell permits are matched -- according to rules to be described below -- to bids to buy permits. The matching system would be computerized, with offers matched one-time per market period.

7.2.3 Exchange

The computer algorithm for performing matching would match orders (and fractions thereof) so as to maximize the sum of the profits made on a bid-asked spread. In mathematical terms, the matching would be made by solving the following mathematical programming problem: [1]

$$\text{maximize:} \quad \sum_i \sum_j (s_{ij}(b_j - a_i) - a_i \bar{s}_{ij}) + \sum_j s_j^{*} b_j$$

$$\text{subject to:} \quad \sum_j s_{ij} + \bar{s}_{ij} \leq A_i \quad \text{for all sources offering to sell}$$

$$\sum_i s_{ij} \leq B_j \quad \text{for all sources offering to buy}$$

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[1] We have formulated the matching algorithm as a linear program matching bids consisting of single point prices. We could as well permit sources to submit schedules of bids, as discussed in Chapters 3 and 4 for expository convenience, and match orders according to the integer programming algorithm described in Chapter 5, Appendix A.

$$\sum_k d_{ik} (o_k + \sum_l s_{lk} - \sum_j s_{kj} - \sum_j \bar{s}_{kj} + s_k^*) < Q_i$$

for all receptors, i

$$s_{ij} \geq 0 \; ; \; \bar{s}_{ij} \geq 0 \; ; \; s_j^* \geq 0$$

where s_{ij} = permit units sold by i to j

$\bar{s}_{ij}$ = permits "absorbed" by the agency in the sale from i to j

b_j = j's bid price for permit units

a_i = i's asked price for permit units

s_j^* = permit units sold by agency to source j

A_i = permit units offered for sale by source i

B_j = permit units bid for by source j

d_{ik} = contributions per unit of source k's emissions to concentrations at receptor i

Q_i = ambient constraint (standard) at receptor i

o_k = permit units held by source k prior to purchases sales

We have assumed in setting up this problem that each source will be permitted to submit only one bid and/or one offer per market period, and that only one bid price and/or one offer price per market period may be quoted. We have also assumed that a match may result in some or all of any order being executed.

Note also that we have defined a quantity variable (denoted $\bar{s}_{ij}$) for the quantity of permits "absorbed" by the agency in any trade. This variable reflects the fact that the quantity of permits yielded by the seller may have to be different than the quantity of permits delivered to the buyer in order to meet ambient constraints. To see why this is so, let us consider a situation in which there are two sources, one of which holds permits for 50 units of emissions and the other of which holds 0 permits. Further, let us suppose that each unit of emissions from the first source translates into 1 unit of ambient concentrations at a single receptor, and that each unit of emissions from the second source translates into 2 units of ambient concentration. Than, if the ambient standard were 50, source 1 would have to transfer 2 permit units for every 1 permit unit delivered to source 2. Otherwise the ambient standard would be violated.

In order to compensate source 1 for selling the requisite number of permits, source 2's bid price would have to be two times source 1's asking price. This indeed is precisely what we should expect on the basis of our mathematical programming analysis of the structure of emissions prices needed to support cost-effective attainment of standards. [1]

The permit-issuing agency will fill any orders which cannot be filled given the offers available, but which could be filled without violating ambient constraints. This is reflected in our mathematical formulation above by the fact that we have included an s_j^* variable which represents sales from the agency direct to the j^{th} source. This formulation insures that the maximum quantity of permits consistent with sources' valuation of them and with maintaining the quality of the environment will be available.

The resale market would, as noted above, work on a periodic basis. Sources would be free to place purchase and/or sale orders, subject to the constraint that more could not be offered for sale than currently were owned. To aid sources in forming expectations about the nature of offers that would result either in additional purchases or sales, a sensitivity analysis would be performed as a part of the matching process. In particular, using the same algorithm that would be used to match offers according to the process described in mathematical terms above, we can calculate the price that would have had to be paid to obtain more permit units than were obtained, other things being equal. We could also calculate the maximum asking price that could have been asked without changing sales, and the asking price that would have resulted in a greater quantity of permits being transferred. The calculation and distribution of this price information should help source operators in formulating their bid and asked price.

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[1] See equation (4.2.6) in Chapter 4. This equation implies that, in the two source one receptor case considered here, equilibrium emissions prices must be in the same ratio as the diffusion coefficients.

7.2.4 Transition to Attainment

Another problem that must be faced in design of a permit system is providing for the transition period to meet the standard. As has been noted above, our calculations show that in Chicago and elsewhere, attainment of the short-term standard depends upon substantial reductions in mobile source emissions and the development of stationary source emission control technology that is now projected to be available in the early to mid-1980's.

There are a variety of ways in which this problem might be handled. One way would be to set a timetable for reduction of maximum ambient concentrations, and implement this timetable by making the ambient constraint progressively more stringent in the algorithm designed above for issuing and reallocating permits. The difficulty with this approach is that the permitting agency is likely to come under substantial pressure to let the timetable slip.

Another approach would be to issue only the number of permits consistent with ambient attainment and supplement the permit program with a charge which would apply to emissions rates over and above those for which permits were held. In the early years of the program, the charge rates would be set to approximate levels slightly in excess of the incremental costs of demonstrated control technology, and would rise over a period of (say) five years to approximate levels slightly in excess of estimated incremental control costs for projected emissions control technology. This approach has a great deal to commend it. It provides a continuing incentive to the development of new technology, and it provides a safety valve should it prove more difficult and/or time consuming to develop advanced emission control technologies than is currently foreseen. It also makes easier the transition to a mature, self-adjusting and self-policing system which we shall discuss below.

7.2.5 Information Requirements

We remarked in the introduction to this chapter that the role of the pollution control agency under a permit system is less active than it is under a charge system. Under the permit system, it sets the rules -- but not the prices. The latter are the result of voluntary exchanges under the rules established by the agency. Our prescription is that opportunities to economize will reveal themselves and become realized through the workings of an impersonal system like that described above. [1]

This feature of permit systems means that the agency does not need to take the initiative to acquire the detailed source-specific cost information that it needs under a charge system. It also need take no action to make fine adjustments to a marketable permit system for inflation, growth, and technical change. Prices, under a marketable permit system, will adjust automatically to changes in costs. This is a decided advantage of a market permit system relative to a charge system.

7.3 Distributional Considerations

Analogously with our findings concerning the nature of an optimal charge system, if we were to perform specific calculations to simulate the workings of a permit system, we would find that in an optimum permit system, similar sources would pay different prices per permit unit for permits. This is because clean air is scarcer in some portions of an air quality control region than others, and the price of this air -- which is reflected in the permit prices paid by sources contributing to pollution in the area -- will be bid up until emissions rates fall to a level consistent with ambient air quality standards. The differences in prices paid per permit unit would reflect the relative scarcity of clean air, as embodied in the trading rules administered by the agency (see Section 7.2 above).

Our results reported in Section 6.5 of Chapter 6 can be recalled here to show that it is important that if a permit system be adopted, something that approximates the optimal system discussed in the preceding section should be chosen. Otherwise, an important source of the efficiency advantages of a marketable permit approach that we normally would hope to reap are lost. [1]

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[1] Since all offers to engage in exchange would be binding (i.e., the agency could force the source to perform as offered), sources would have an incentive not to misstate willingness to engage in transactions, since misstatement could result in losses.

One other distributional consideration that arises in the design of a permit system concerns the question of who will own the permits. There are two possibilities. First, sources could own permits, and transfer ownership just as they would any other property. The principal advantage of this alternative is that if (initially) permits are granted rather than auctioned, all existing sources are in effect being given valuable property. This could be an important consideration in gaining acceptance for the concept. Another advantage is that it is likely to create a greater sense of certainty and security concerning sources' rights and responsibilities relating to air pollution control. A disadvantage of source ownership is that the government loses much of its flexibility to adjust standards in light of new information. For example, if it were determined subsequently that a standard of $200 \mu g/m^3$ were necessary to protect the public health and welfare, then conceivably the government could have to seek to buy or to condemn enough permits to meet the more stringent standard.

A second alternative for ownership is that the permits remain the property of the permit-issuing authority, with sources leasing permits from the agency. This solves the problem of possible inflexibilities caused by source ownership of permits, but of course at the expense of giving up the advantages that source ownership could confer.

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[1] It would still, however, retain its advantages as an effective and efficient policy instrument in the presence of uncertainty, and as an effective and efficient policy instrument for stimulating the development and application of emissions control technology.

On balance, we think it important that the permitting agency retain the flexibility of a lease system. Changes in information (or errors) can be more easily accommodated. This also tends to limit windfall profits from trading in permits.

7.4 Frequency of Market Operation

We noted in Section 7.2 that the market for exchange of permits is to operate on a periodic basis. We left open the question, however, of how frequently the market should operate. On the cost side, there clearly are costs associated with increasing frequency. We suspect that these are minor compared to the fixing costs of establishing the exchange market capability (see Section 7.7 below on this point). The benefit of frequent operation is that it permits sources to adjust the quantities of permits they hold in light of information about market opportunities. Clearly there will be considerable uncertainty, particularly when an exchange market starts up, about the bids that will be necessary to secure different quantities of permits. Frequent operation of markets will permit sources to reduce this uncertainty, with the result that permit allocations should more nearly correspond to those required to implement efficient pollution abatement. Results reported in Chapter 5 and Chapter 6 have shown that improved allocations can result in huge savings.

In this section we show how reduced uncertainty leads to improved allocations and present some rough estimates for individual sources of the magnitudes of savings involved.

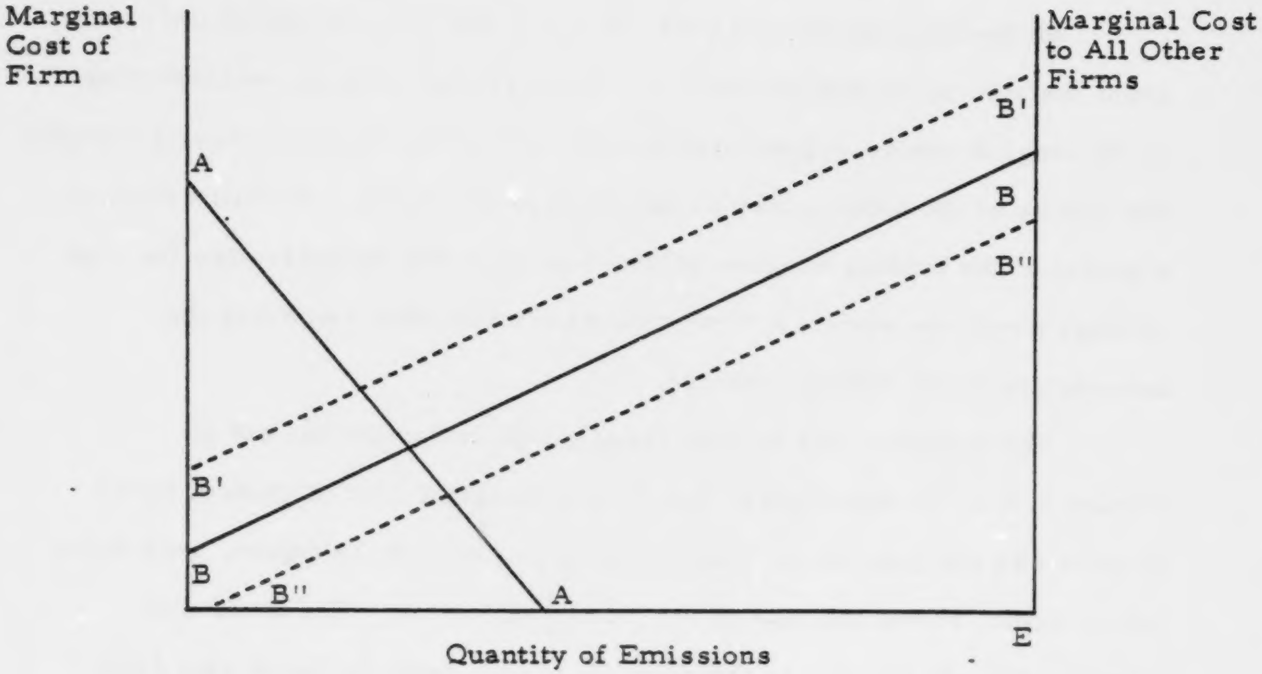
The problem we will discuss is this: Consider an incentive system in which, at the beginning of each period, each source makes a two-part bid for emissions permits. The first part of the bid consists of a price offered for emissions permit units. The second part is a limit on the maximum number of permit units to which the offer price applies. The control authority then takes all the bids from the sources and allocates permits to sources in such a way that no source receives more than the stated maximum. Each source pays an amount equal to the number of permits received times the source's bid price.

At the time the source bids, it (i.e., the source) will be uncertain about the size of its final allocation. If the period between recontracting is too long, it can be argued that bidders will be much more uncertain about the effects of the bidding than about the cost of control. We will construct a model of the bidding process below, and show how to determine the cost savings (from the source's viewpoint) associated with removing the uncertainty of the bidding process.

The problem may be addressed graphically with the aid of Figure 7.4.1. In this figure, the firm's marginal cost of control curve is shown as the line A-A. Notice that the x-axis of the figure, read from left to right, shows the size of the firm's allocation. The maximum allocation to all sources is the point E. If we read the same axis from right to left, we have the size of the allocations of permits to all other sources. Their marginal cost of control, an aggregate of the individual cost of control curves, is the line B-B in the figure, sloping downward to the left. (In fact, the line B-B need not represent an aggregate of marginal cost curves, it could be based on behavioral considerations as

Figure 7.4.1

Uncertainty Analysis



well. What matters in the analysis below is that it summarizes the source's beliefs about the outcomes of the bidding process.)

After all the bids are opened, the fact that the true curve was B-B is revealed to the source. However, the source cannot know this for certain ex ante. Instead, the source might think that the true curve was given by the B'-B' (i.e., that the other sources had a higher demand than was actually the case), or that the true curve was B''-B'' (the other sources' demand was thought to be too low). Because of this uncertainty, we will see that the source makes choices that are different from those that would be made under certainty. We will see that reducing the uncertainty is worth something to the bidder, and that it might be worthwhile to reduce it by more frequent recontracting.

7.4.1 The Basic Model

We will begin by formulating the problem in general. After a brief discussion of it in this form, we will work an example cost calculation to show the possible magnitude of the losses. The basic decision-making unit we will consider is a firm in a competitive industry. Since we are interested in analyzing the effect of uncertainty on the emissions decisions of the firm, we will assume that the output of this firm is fixed. This enables us to work the problem as one of cost minimization instead of profit maximization.

To summarize the relationship between output, emissions, and uncertainty, we will assume that the firm's production costs are given by a function $C(e)$, where e is the quantity of emissions. Obviously, this cost function depends on the price of factors of production other than emissions. Our implicit assumption is that these prices are known, and their quantities may be smoothly and costlessly adjusted as circumstances dictate. [1] In addition, we make the following explicit assumptions about the derivatives of the cost function:

1. $C'(e) \leq 0$ -- The marginal cost of emissions is non-positive. (If this were not so, it would be optimal to reduce emissions to zero.)
2. $C''(e) > 0$ -- The marginal cost of emissions increases with increased emissions levels.

In addition to these costs, the firm will pay a price of q per permit unit of emissions, up to an amount e_o of permit units. The pair (q, e_o) constitutes its bid. This means that the firm's total costs for emissions are:

$$T(e;e_o,q) = \begin{cases} C(e) + qe & \text{if } e \leq e_o \\ C(e_o) + qe_o & \text{if } e > e_o \end{cases} \qquad (7.4.1.1)$$

where the notation on the left-hand side of the equation indicates that both e_o and q may be chosen, and that the number of emissions permits that would otherwise be allocated to the firm is e. [2]

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[1] This amounts to assuming that factors may always be adjusted after the state of the world u is known. Without this assumption, we would have to consider the effect of uncertainty on factor use, as in McCall (1971). However, if factors cannot be costlessly adjusted *ex ante*, an appeal to the Samuelson-LeChatlier Principle suggests that our estimates of loss will be too low.

[2] We could at this point make an additional assumption about the firm's attitude toward risk. For example, following Sandmo (1971(and Leland (1972) we could assume that the Von-Neuman/Morgenstern utility of profits is $U(\pi)$.

However, in this case losses sustained by the firm would depend on its attitude toward risk. Since these attitudes are not observable, and cannot enter empirical estimates of losses, there is little to be gained from considering risk attitudes at the theoretical level.

Finally, we need to summarize the firm's assessment of the bidding situation. We do this by defining a probability density function $f(e;q)$. Its corresponding cumulative distribution $G(e;q)$ is the probability that the allocation will exceed e when the price that the firm bids is q. A very reasonable assumption to make is that this probability will not decrease if the firm raises its bid. In terms of derivatives, this assumption is:

$$(7.4.1.2) \qquad G_q(e;q) \geq 0 \ .$$

In general, $G(e;q)$ is a decreasing function of the emissions allocation e; if there is no uncertainty the decrease occurs as a step from one to zero, at the level of emissions given by a "supply curve" $S(q)$. That is, if there is no uncertainty $G(e;q) = 1$ if $e \leq S(q)$, and $G(e;q) = 0$ if $e > S(q)$.

7.4.2 Analysis When There is Uncertainty

In this section we assume that there is uncertainty about the bidding process, and find out what the firm's optimal choices of q and e_o are. To do this, we calculate the expected cost of emissions, and find the cost-minimizing decisions.

The expected cost can be found by taking the expected value of $T(e;e_o,q)$, as defined in Equation (7.4.1.1). This gives:

$$(7.4.2.1) \qquad \overline{T}(e_o,q) = \int_0^{e_o} [C(e) + qe]f(e;q)de$$

$$+ [C(e_o) + qe_o]G(e_o;q)$$

The first term in this equation includes the emissions costs when the allocation is below e_o, while the second term is the costs when emissions are e_o times the probability that this event occurs.

To find the expected cost minimizing choices of q and e_o, we differentiate Equation (7.4.2.1). This gives (after some algebra) the following necessary conditions:

$$(7.4.2.2) \qquad G(e_o;q)[C'(e_o) + q] = 0$$

$$(7.4.2.3) \qquad \int_0^{e_o} [C(e) + qe]f_q(e;q)de + [C(e_o) + qe_o]G_q(e;q) + \int_0^{e_o} G(e;q)de = 0$$

Since we are considering the case where uncertainty is present, we can assume that $G(q;e_o)$ in Equation (7.4.2.2) is non-zero. Then Equation (7.4.2.2) can be re-written:

$$(7.4.2.4) \qquad C'(e_o) + q = 0$$

This means that the limit e_o is chosen so that the marginal cost of emissions control $(-C'(e_o))$ equals the bid price q.

We can sharpen and interpret Equation (7.4.2.3) by assuming that the uncertainty about the bidding process takes a specific form. In particular, suppose we can represent it by the certain or "true" supply function $S(q)$ plus additive noise u. Formally, we model the firm's allocation as $e = S(q) + u$, where the probability density function of u is $\phi(u)$, and we further assume that u has zero mean. This means that:

$$(7.2.4.5) \qquad f(e;q) = \phi(e - S(q))$$

$$G(e;q) = 1 - \Phi(e - S(q))$$

where $\phi(u)$ is the probability distribution function of u.

In terms of this special model, the necessary conditions for an optimum become:

$$(7.4.2.6) \qquad [C'(e_o) + q]\,[1 - \Phi(e_o - S(q))] = 0$$

$$(7.2.4.7) \qquad \int_0^{u_o(e_o,q)} [C'(u + S(q)) + q]\, S'(q)\phi(u)du + \int_0^{u_o(e_o,q)} [u + S(q)]\phi(u)du = 0$$

where:

$$u_o(e_o, q) = e_o - S(q)$$

is the critical or threshold value of the random variable, which corresponds to e_o in the more general model.

Noting that $C'(e) \leq 0$, we can re-write Equation (7.4.2.7) in a more recognizable way as:

$$(7.2.4.8) \qquad -\int_0^{u_o(e_o,q)} C'(u + S(q)]\phi(u)du = \left[q + \frac{S(q)}{S'(q)}\right] \Phi \left[u_o(e_o,q)\right] + \frac{1}{S'(q)}\int_0^{u_o(e_o,q)} u\phi(u)du$$

assuming $S'(q) \neq 0$.

The term on the left-hand side of Equation (7.4.2.8) is the expected marginal cost of control, while the term on the right-hand side is the expected marginal price of permit units. The necessary condition requires q to be set so that these two marginal costs are equal. Notice, moreover, that the expected marginal price of the permit units may be more than the bid q because $S'(q)$ may be non-zero.

7.4.3 Analysis When There is No Uncertainty

Equations (7.4.2.6) and (7.4.2.8) show us how the necessary conditions appear when there is no uncertainty. In this case e_o can be ignored, because it can always be set to yield exactly the desired allocation. 1/ The optimal choice of q is the solution to

$$(7.4.3.1) \qquad [C'(S(q)) + q]\, S'(q) + S(q) = 0$$

or, converting to the form of Equation (7.2.4.8):

1/ This does not violate Equation (7.4.2.6), nor Equation (7.4.2.2) for that matter, because $G(e_o;q) = 0$ at the optimum.

(7.4.3.2) $$-C'(S(q)) = q + S(q)/S'(q)$$

In the certainty case the marginal cost of control, $-C'(e)$, is set equal to the marginal price of emissions permits, which can be written $q(1 + 1/\eta)$ where η is the elasticity of the supply function, $\eta = qS'(q)/S(q)$.

7.4.4 Value of Reducing Uncertainty

We may ask, on average, what the difference between the solutions under uncertainty and under certainty is to the firm. By "on average" we mean: if the firm's assessment of the uncertainty were correct, but it could make the optimal choice under certainty, what would be the cost saving, averaged over many bids?

To calculate this quantity, we set u, and let $q^*(u)$ be the optimal solution when the supply curve is known ex ante to be $e = S(q) + u$. This solution satisfies the analog of Equation (7.4.3.1):

(7.4.4.1) $$\{C'[u + S(q^*)] + q^*\} S'(q^*) + [S(q^*) + u] = 0$$

To find the average value of emissions costs, we evaluate

(7.4.4.2) $$\int_0^\infty C[u + S(q^*(u))] + q^*(u)\,[u + S(q^*(u))]\phi(u)du$$

and compare it with average costs under uncertainty, which are given by Equation (7.4.2.1).

7.4.5 An Example

To see how the model works, let us work a simple but reasonable example. We make the following assumptions about the functional form:

(7.4.5.1) $$S(q) = S_0 + S_1 q \qquad S_0, S_1 > 0$$

(7.4.5.2) $$C(e) = C_0 - C_1 e + 1/2\, C_2 e^2 \qquad C_0, C_1, C_2 > 0$$

(7.4.5.3) $$\phi(u) \sim N(0, \sigma^2) \qquad \sigma > 0$$

That is, the marginal cost of control curve is approximated by a quadratic function and the supply function by a linear function. The firm's uncertainty is characterized by a normal distribution, and the variance of e is σ^2, independently of q. [1]

To find a solution, we first solve for e_o given q using Equation (7.4.2.6). This gives:

(7.4.5.4) $$e_o = \frac{q + C_1}{C_2}$$

Hence the threshold $u_o(e_o, q)$ is

(7.4.5.5) $$u_o = \frac{q + C_1}{C_2} - (S_0 + S_1 q) = (C_1/C_2 - S_0) + (1/C_2 - S_1)q$$

$$= a_0 + a_1 q$$

---

[1] Because the normal variable u is defined on $-\infty < u < \infty$, we should worry about the lower limit of integration. We will not do so, implicitly assuming that we are far enough from the origin of e for its effect to be negligible. A check on this assumption can be obtained by comparing the final average level of emissions to σ.

where $a_0 = (C_1 - S_0 C_2)/C_2$ and $a_1 \doteq (1 - S_1 C_2)/C_2$.

The optimal value of q_o is found from Equation (7.4.2.8) as follows:

$$\int_0^{u_o(e_o, q)} \{C'[u + S(q)] + q\} S'(q)\phi(u)du = \int_{-\infty}^{u_o} [-C_1 + (u + S_0 + S_1 q)C_2 + q]\phi(u)du$$

$$= \Phi(u_o)[-C_1 + S_0 C_2 + qC_2 S_1 + q]S_1$$

$$+ \Psi(u_o)C_2 S_1$$

$$\int_0^{u_o(e_o, q)} [u + S(q)]\phi(u)du = \Psi(u_o) + (S_0 + S_1 q)\Phi(u_o)$$

where:

$$\Psi(u_o) = \int_{-\infty}^{u_o} u\phi(u)du \ .$$

Using these functions, Equation (7.4.5.5) becomes:

(7.4.5.6)
$$\phi(a_0 + a_1 q)[-C_1 S_1 + S_0 C_2 S_1 + S_0 + q(2S_1 + C_2 S_1^2)]$$

$$+ \Psi(a_0 + a_1 q)(1 + C_2 S_1) = 0$$

which can be solved recursively for q as:

(7.4.5.7)
$$q = \frac{C_1 S_1 - S_0(1 + C_2 S_1) - (1 + C_2 S_1)M(a_0 + a_1 q)}{2S_1 + C_2 S_1^2}$$

where $M(u_o) = \Psi(u_o)/\phi(u_o)$ is the conditional expected value of the random variable u given $u \leq u_o$.

When $e = S(q) + u$, with u known, the necessary condition equivalent to Equation (7.4.3.1) is:

$$(7.4.5.8) \qquad (q - C_1 + C_2 (u + S_0 + S_1 q))S_1 + u + S_0 + S_1 q = 0$$

Hence

$$(7.4.5.9) \qquad q^*(u) = \frac{S_1 C_1 - S_0(1 + C_2 S_1) - u(1 + C_2 S_1)}{S_1 + S_1(1 + C_2 S_1)}$$

(Notice the similarity between $q^*(u)$ and the recursive equation for the optimal q under uncertainty.)

In order to provide some rough idea of the possible savings associated with reductions in uncertainty, we have made some approximate calculations of the relationship between uncertainty and expected cost for a representative source. The results of these calculations are shown below in Table 7.4.5.1. As can be seen from this table, the excess costs associated with uncertainty can be quite large, in some cases amounting to more than 50 percent of control costs under certainty.

Table 7.4.5.1
Comparison of Costs Under Certainty and Uncertainty
for a Hypothetical Source

Standard Error in Market Supply	Cost of Control Under Certainty (millions)	Cost of Control Under Uncertainty (millions)	Excess Cost Due to Uncertainty (millions)
10	7.1	11.5	4.4
5	7.2	8.7	1.5
2	7.3	7.7	0.4
1	7.3	7.5	0.2

7.4.6 Conclusion

While we cannot demonstrate rigorously that frequent operation of the market will tend to reduce uncertainty, we believe that frequent operation will provide information that will improve bidders' knowledge of supply and demand conditions in permit markets. Since the cost of operation of the market is small in relation to the cost of setting it up in the first place, and the costs of uncertainty potentially are huge, we recommend daily operation of the market.

7.5 Additional Safeguards Against Uncertainty

We concluded in the preceding section that daily market operations should help to insure that sources' uncertainty about market opportunities does not prevent the market from reaching an equilibrium that is roughly consistent with minimization of control costs. Three important classes of problems associated with uncertainty still remain, however.

First are the problems associated with uncertainty about future prices and availabilities of permits. Firms contemplating the expansion of existing facilities or construction of new facilities clearly need to be able to plan their emissions controls and permits needs, and to insure that plans and outcomes are roughly consistent.

The second class of problems that arises relates to the fact that there is a present uncertainty about the date by which compliance with a stringent short-term NO_2 standard will be feasible economically. Our analysis in Chapter 5 showed that attainment through emissions controls (as opposed to shutting down of sources) will require technologies that are PROJECTED (not known) to be available at reasonable cost in the early to mid 1980's. What happens if these projections are wrong and the number of permits issued is so few relative to what can be achieved at reasonable costs that control costs become astronomically high? Some safeguard against this eventuality needs to be built into the system.

The final class of problems that arises from uncertainty is that instances may occur in which a source emits an amount greater than that to which it is entitled by the permits it holds. This could happen, for example, due to accidental failure of emissions control equipment. Some way needs to be found to discourage excursions above permitted amounts without bringing into play the cumbersome machinery of civil or criminal penalties that incentive approaches are designed to avoid. Ideally, we would like the permit program to be as close to self-policing as possible, with incentives to behave properly built directly into the functioning of the marketable permit program.

Each of the problems discussed above can be dealt with in a relatively straightforward fashion. The obvious solution to the first problem is for firms to buy the permits they will need for projected activities and hold them. This certainly eliminates some uncertainty. At the same time, however, it is very costly since permits would be held idle that quite possibly could be used for valuable productive purposes. Clearly a more efficient alternative would be to establish a market in which firms can buy permits for future delivery which, in the interim, could be used elsewhere. This is the idea behind a "futures" market, which was discussed briefly in Chapter 3.

A futures market could also be used to help solve the problem of transition to attainment (see Section 7.2.4 above). Instead of restricting the number of permits issued to the maximum number consistent with bids obtained and ambient standards, a number of permits that declines gradually to this number over a period of years might be issued. This could be done by applying gradually tighter air quality constraints in matching offers to buy and sell futures markets.

A futures market could be introduced relatively easily into the basic market framework we have outlined in Section 7.2 of this chapter. Offers to buy and sell simply would be dated in the formulation presented in Section 7.2.3.

If it were deemed to be desirable, still another safeguard against uncertainty could be introduced into the system through organization of a market in options. This market would permit firms to guarantee future price and availability (just as does the futures market), but without any contractual obligation to perform at a future date unless the option is exercised. Option puts and calls, along with futures "sells and buys" and spot "sells and buys" would be matched according to the same rules as discussed in Section 7.2.3. At the time that transition to attainment is completed, no transaction would be allowed which could result in an allocation of permit units, in the present or in the future, which would result in a violation of ambient standards.

Our approach to dealing with uncertainty about future permit market developments is thus to emulate approaches in other markets. We do this by creating contracts to complement the spot contracts discussed in Section 7.2 which facilitate the spreading of risk. The cost of this is that the market becomes more complicated since a richer variety of trades becomes possible. The benefit, of course, is that resources may be allocated more efficiently.

Futures contracts and options contracts will do little to alleviate uncertainty about the cost of emissions control technology adequate to meet a stringent short term NO_2 standard. They also do nothing to help resolve the problem that arises because of the possibility of random accidental failures to comply with permits. While these two classes of problems may appear to be different, they are in fact quite similar, and the solutions we will propose to them therefore are very similar.

The key to the solution of these problems is to recognize that both are problems which arise because the costs of emissions reductions turn out to be very high. In the first case, high cost is a chronic problem resulting from the failure to develop effective low-cost emissions abatement technology. In the second case, high cost is transitory, resulting from a temporary failure of control systems or other departure from normal operations.

The design problem is to design an "automatic escape valve" which provides continuing incentives to abate emissions but provides an escape in the event that costs are ruinously high. We hasten to add that were concentrations of NO_2 in excess of the standard thought to be toxic or otherwise highly dangerous, it would be inappropriate to provide an escape. Since the evidence on health effects briefly reviewed in Chapter 2 does not seem to support this conclusion, and the risks that costs of control could be very high are non-negligible, we think the escape valve solution we will propose is warranted.

The basic idea behind the escape valve concept is this. The permit-issuing authority sets a price at which it is willing to lease additional permit units to all comers. This price should be set sufficiently high to induce emitters to reduce emissions to the maximum feasible extent and to provide an inducement for the development of new control technology. If a source exceeds the quantity of emissions for which it holds permits, this higher price would apply to all emissions in excess of permit entitlements. This levy would be interpreted as an automatic surcharge, not as a penalty, and would be automatically assessed.

The most effective design for the escape valve would be to set the price of excess emission rates equal to the estimated marginal cost of maximum demonstrated emissions control. This is basically the suggestion we have made in Section 7.2.4 for the period during transition to attainment, and it also seems to be a sensible solution to providing for any transitory difficulties in maintaining emissions controls.

7.6 Legal Considerations

Many states already operate permit systems as a part of their regulatory system for implementing pollution control. Permit systems are also expressly authorized by the Clean Air Act Amendments of 1977 (See Section 110 of the Clean Air Act Amendments). Thus, the basic concept of a permit system is certainly consistent with the law of air pollution control, and is familiar to virtually all regulatory pollution control authorities.

What is new about the permit system we have been discussing is the means by which permits are obtained. Under the regulatory approach, permits are granted by the permitting authority on the basis of plans and policies established by the authority to meet environmental standards. Under the market-based approach investigated here, permits would be leased to sources on the basis of competitive bidding, subject to the constraint that no more permit units would be leased than would be consistent with the attainment and maintenance of ambient standards.

We, thus, foresee no legal problems that would block the adoption and effective operation of a permit program like that we have outlined in this chapter. This conclusion was also reached by de Lucia in his review of the practical problems associated with the adoption of a permit system as a water pollution control tool. As with environmental control strategies in use currently, de Lucia notes that the permit program could rely on the Commerce clause as the constitutional basis for enacting legislation. There appears to be a little hindrance to the establishment of a constitutionally secure permit program. de Lucia's chief concern is that sources may challenge the legality of the permit system on the grounds that it represents "an unconstitutional taking of his property without compensation, in violation of due process rights..."[1/] However, de Lucia dismisses this possibility by pointing out that the program does not prohibit (make illegal) effluent discharges. Rather, it is simply a scheme for allocating a scarce resource (in this instance the atmosphere) in an economically efficient manner among competing users. The air mantle is not a free good, and the cost of the permit is nothing more than a cost of doing business.

[1/] de Lucia (1974), p. 136.

7.7 Public Administration Considerations

The elements necessary for the implementation of an effective emissions permit program are detailed in Figure 7.7.1. There are essentially three stages to this implementation. First, the agency issues permits; second, provision is made for the trading of emissions permits between sources with the agency acting as the middleman; and third, reallocation of permit holdings are allowed through subsequent bid and ask orders.

Figure 7.7.1

Flow Diagram for Emissions Permit Program

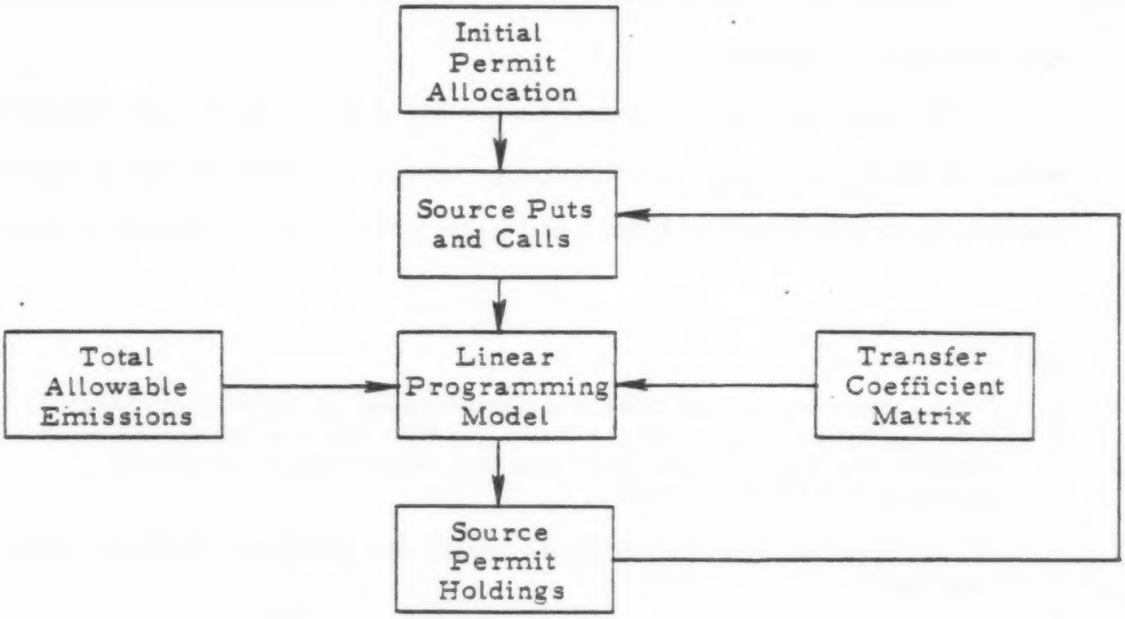
Initial Permit Allocation
Source Puts and Calls
Total Allowable Emissions
Linear Programming Model
Transfer Coefficient Matrix
Source Permit Holdings

Table 7.7.1 shows the level of expenditures that would be needed to administer an emissions permit program. [1], [2] As with the charge program, we employed the methodology developed by Lynn and Deane to describe the agency administrative activities. [3] However, the types of activities with which the agency must now concern itself differ somewhat from the charge approach, especially with respect to source-related activities.

The source category activities for the permit program include:

- Permit Transactions
- Stack Testing
- Source Review
- Legal Action

The monitoring and management related activities are as defined for the charge strategy. [4]

The procedures we used for converting these tasks into manpower and cost estimates follow the same approach as with the charge program. Staffing formulas found in Lynn and Deane were used to determine manage-

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[1] Note, there are other possible descriptions of a permit program. For example, rather than a fixed quantity constraint for an entire region, the agency may partition the region into a series of permissible trading zones.

[2] These figures refer to all three levels of agencies: Federal, state, and local.

[3] Lynn and Deane (1975).

[4] See Section 6.10, pp. 6-63 to 6-71.

Table 7.7.1

Manpower and Cost Requirements for Emissions Permit Program, Chicago AQCR (1978 dollars)

	Man-Years	Cost
A. Initial Costs		
Dispersion Modeling	.24	$ 5,000
Quantity Constraint	.16	4,000
Initial Allocation	.16	4,000
Equipment Expenditures	-	200,000
Total	.56	$213,000
B. Recurring Costs		
Management	33- 41	$410,000- 529,000
Monitoring	8- 15	108,000- 207,000
Source-Related Activities	26- 55	379,000- 800,000
Total	67-111	$897,000-1.536,000
First Year Total		$1,110,000-1,749,000
Recurring Total		$ 897,000-1,536,000

ment and monitoring manpower levels. [1] For source related activities, we defined manpower coefficients, applicability factors and frequenty factors for each of the permit activity categories. These factors are shown in Tables 7.7.2 and 7.7.3.

Finally, cost information was derived through use of annual salaries as reported in the Air Pollution Control Strategy Resource Estimator model (1977). Again, these costs were inflated to 1978 dollars so as to retain comparability with our control cost estimates of Chapter 5.

It should be pointed out that for the permit transactions activity, we assume that the "market" operates each regular work day. Additionally, we assume that each source submits some form of bid every trading day. [2]

The total cost to administer a permit program in the Chicago AQCR ranges from about $900,000 to $1.5 million annually. This is slightly higher than the corresponding optimal charge program we have described. The difference can be traced to increased administrative duties required of the agency in maintaining close scrutiny over emissions permits holdings and coordinating permit transactions. [3]

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[1] Given the duties of the agency in permit transactions and the agency responsibility of knowing who owns which permits, the magnitude of management expenditures will be higher under the permit program relative to the charge program.

[2] Other non-source groups can be market participants. It is difficult to gauge how many bids will be submitted by such groups and thus how many additional man-hours will be devoted to processing the bids. By estimating man-hours as if each source bid every day, perhaps the effect of these other bidders can be partially accounted for.

[3] As described earlier, with each bid a source will be given information on, for example, the number of additional permits he could have obtained with a slightly different bid.

Table 7.7.2

Manpower Factors for Stationary Source Activities - Time (Hours) Per Unit Performance Per SCC - Emissions Permit Program

Source Type a/	Activities			
	Permit Transactions			
	Source to Agency	Stack Testing	Source Review	Legal Action
1. Utility, Coal >10 MMBtu/hr (21)	.125-.25	32-64	12-24	200
2. Utility, Oil & Gas >10 MMBtu/hr (11)	.125-.25	32-48	12-24	200
3. Industrial Coal >100 MMBtu/hr (60)	.125-.25	32-48	12-24	200
4. Industrial Coal 10-100 MMBtu/hr (37)	.125-.25	24-40	12-24	200
5. Industrial Oil & Gas >100 MMBtu/hr (109)	.125-.25	24-40	10-20	200
6. Industrial Oil & Gas 10-100 MMBtu/hr(420)	.125-.25	20-32	10-20	200
7. Gas Turbines (11)	.125-.25	20-32	10-20	200
8. Industrial Processes (116)	.125-.25	16-32	10-20	200
9. Nitric Acid (8)	.125-.25	16-32	10-20	200
10. Municipal Incinerator (4)	.125-.25	16-32	10-20	200

a/ Numbers in parentheses are total number of sources in category.

Table 7.7.3

Applicability Factors for Stationary Source Activities - Percentage of Sources Subject to Activity - Emissions Permit Program

Source Type a/	Activities			
	Permit Transactions			
	Source to Agency	Stack Testing	Source Review	Legal Action
1. Utility, Coal >10 MMBtu/hr (21)	Daily	100	25-50	4-8
2. Utility, Oil & Gas >10 MMBtu/hr (11)	Daily	100	25-50	4-8
3. Industrial Coal >100 MMBtu/hr (60)	Daily	100	25-50	4-8
4. Industrial Coal 10-100 MMBtu/hr (37)	Daily	100	25-50	4-8
5. Industrial Oil & Gas >100 MMBtu/hr (109)	Daily	50-100	10-25	4-8
6. Industrial Oil & Gas 10-100 MMBtu/hr (420)	Daily	50-100	10-25	4-8
7. Gas Turbines (11)	Daily	50-100	5-15	4-8
8. Industrial Processes (116)	Daily	50-100	5-15	4-8
9. Nitric Acid (8)	Daily	50-100	5-15	4-8
10. Municipal Incinerator (4)	Daily	50-100	5-15	4-8

a/ Numbers in parentheses are total number of sources in category.

In relation to a regulatory system, the estimated costs needed to administer a marketable permit program are lower. As was the case for the charge program examined in Chapter 6, the effort expended by control agencies in negotiating, promulgating, and enforcing compliance schedules accounts for the difference in costs.

7.8 Conclusions

This chapter brings us to the end of our examination of alternative policy instruments for implementing a short-term NO_2 standard. Our major findings in this chapter, which has focused on marketable permit systems, are these.

First, a marketable permit system designed along the lines described in Section 7.2 would provide an efficient and effective policy instrument for implementing a short-term NO_2 standard. The system we have proposed provides for the control agency to operate a market in which orders to buy and sell permits denominated in emission rates, both spot and future, would be matched according to rules designed to maximize economic welfare from the utilization of the scarce air resource. Strictly speaking, permits would not be "bought" and "sold", but rather only "leased" and "subleased"; the agency would retain "ownership" of them.

Ideally, the only constraint on the operation of the system would be that no exchange would be made which would result in violation of ambient standards. Other constraints on exchanges would erode some of the efficiency advantages of a marketable permit system. (Our results from Chapter 6 can be recalled here for evidence on this point.)

If, for whatever reason, it is necessary to consider marketable permit system designs that do not approximate the ideal, it should not be concluded that the economic case for a marketable permit policy as an alternative to regulatory policies is weakened. A marketable permits policy still retains the inherent advantages that it tends to be lower cost in the presence of uncertainty, that it provides natural vehicles (via futures and options markets) for dealing with uncertainty about the future, and that it tends to be more effective in inducing the development and adoption of new, more effective emissions control technology.

A second important conclusion of our analysis is that the incremental costs directly attributable to the administration of a marketable permit system like that we have designed are likely to be of the same order of magnitude as the incremental cost of implementing an effective regulatory policy. In absolute amount, we estimate the cost of a marketable permit policy to be slightly less than that of a regulatory policy. While our estimates of these costs are at best approximate, a comparison of their rough magnitude with the estimated magnitudes of control costs under different policies suggests that refinements would not change our conclusion that a marketable permits policy is superior on the basis of cost-effectiveness to a regulatory policy.

A third conclusion of our analysis is that a marketable permits policy appears to possess an important practical information advantage over both charges policies and regulatory policies. Under the latter types of policy, the agency must make studies or determine by other means individual sources' control costs, and update these costs continuously to reflect inflation and technical change.[1/] Moreover, in order to accommodate growth, the agency must attempt to forecast the entry, exit, and expansion/contraction decisions of firms. Our brief discussion of these information requirements in Chapter 6 suggests that, at best, agency estimates of these data will be very imprecise.

The practical information advantage of a marketable permits policy is that the agency does not need to perform studies or otherwise take steps to determine these data in order to implement the policy. Instead, the requisite data are automatically revealed on voluntary (but binding) offers to engage in exchanges. If we assume, as seems reasonable, that sources possess better information than agencies about key parameters (e.g., control costs, opportunities for technical change, effects of inflation on control costs, plans to enter/exit/expand/contract, etc.), then we might conclude that the automatically-generated market signals and emissions allocations arising from operation of a marketable permit system would be superior to an emissions charge system. Here we can recall the results of our analysis in Section 4.3, which shows that if sources possess and reveal perfect information in the operation of the market, an *ex post* optimal allocation of emissions is assured.

This does not mean that an agency is relieved of all responsibility for gathering of information. Cost information (of a more general sort) would still be required for purposes such as ambient standard evaluation,

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[1/] Strictly speaking, an agency needs this information under a regulatory policy only if it is concerned about the cost consequences of its actions. Clearly, agencies responsible for environmental regulation in the U.S. *are* concerned about costs.

or investigation of the economic costs of current programs. Precise information on the population of sources, on the contribution of sources to receptors, and on the actual emissions of sources would still be required, just as it is under emissions charges and regulatory policies.

A final conclusion to which we wish to draw attention here is that it is relatively easy to provide a means by which sources can insure against future uncertainties under a marketable permits system. This can be done by permitting trades in "futures" and "options". A firm could, for example, guarantee the price at which permits could be purchased for a source to be constructed in the future through transactions in these markets. There seems to be no natural way to accomplish this easily under either a charges or a regulatory policy.

REFERENCES TO CHAPTER 7

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CHAPTER 8

CONCLUSIONS

8.1 Introduction

Our report has covered a good deal of ground and many conclusions have been stated in each of the preceding chapters. In this chapter, we will try to restate and explain briefly each of the major conclusions which we believe to be justified on the basis of our analysis.

8.2 Conclusions

Our major conclusions are as follows.

ATTAINMENT AND MAINTENANCE OF A SHORT-TERM NO_2 STANDARD OF 250 $\mu g/m^3$ POSES A SERIOUS PROBLEM.

ATTAINMENT AND MAINTENANCE OF A SHORT-TERM NO_2 STANDARD OF 500 $\mu g/m^3$ DOES NOT APPEAR TO POSE A PROBLEM.

Studies show that 202 AQCR's may have one hour concentrations of NO_2 in excess of 250 $\mu g/m^3$. That is, approximately 4 out of 5 AQCR's may be in non-attainment status.

At a standard of 500 $\mu g/m^3$, very few regions would be in non-attainment status, and the cost of bringing these regions into attainment status would be low. Under these circumstances, consideration of alternatives to current regulatory approaches to pollution control for implementing a short-term NO_2 standard would be unwarranted due to the costs of policy change. Accordingly, the balance of our conclusions are predicated on the condition that a short-term standard is set that is sufficiently low to place a number of regions in non-attainment status and that the costs of attainment in these regions are significant.

> APPLICATION OF CURRENTLY AVAILABLE EMISSIONS CONTROL TECHNOLOGY WILL NOT SUFFICE TO ATTAIN AN AMBIENT STANDARD OF 250 $\mu g/m^3$ IN MANY AQCR'S. APPLICATION OF STATIONARY SOURCE CONTROLS PROJECTED TO BE AVAILABLE IN THE EARLY TO MID-1980's WILL BE REQUIRED.

Our data show that between 66 and 84 AQCR's would not attain a 250 $\mu g/m^3$ standard by 1982, and that between 26 and 50 would not have attained this level by 1990 using currently available emission controls in conjunction with the emissions controls to be applied to mobile source emissions.

This clearly points to the need to develop more effective emissions control technology for stationary source emissions of NO_x.

> ADEQUATE TECHNOLOGY FOR CONTINUOUS MONITORING OF NO_x EMISSIONS IS CURRENTLY AVAILABLE AND THE COST OF THIS TECHNOLOGY (EXPRESSED ON AN ANNUAL BASIS) IS LESS THAN 25 PERCENT OF THE ANNUAL COST OF EMISSIONS CONTROL PROJECTED TO BE REQUIRED TO MEET SHORT-TERM STANDARDS.

We see no monitoring barriers to either regulation or pricing of emissions of stationary source NO_x emissions. Adequate technology is currently available, and the cost of this technology is not large in relation to the control outlays that will be required to meet stringent short-term standards. We believe that the cost of continuous monitoring certainly will be less than 25 percent of control costs, and more likely on the order of 5 to 10 percent of these costs.

EMISSIONS CONTROL STRATEGIES THAT TAKE ACCOUNT OF DIFFERENCES IN SOURCES' INCREMENTAL COSTS OF CONTROL AND INCREMENTAL CONTRIBUTIONS TO AMBIENT CONCENTRATIONS CAN ACHIEVE SHORT-TERM AMBIENT STANDARDS AT SIGNIFICANTLY LOWER TOTAL COST THAN CAN STRATEGIES WHICH DO NOT TAKE ACCOUNT OF THESE DIFFERENCES.

Our quantitative analysis of emissions control strategies in Chicago shows that a least cost strategy (which is designed to take account of cost and ambient contribution differences) is about one-fourth as costly as a strategy which reflects what might be achieved under today's sophisticated regulatory implementation planning methods, and only about one-tenth as costly as the strategy that reflects today's crudest regulatory implementation planning methods. In absolute terms, we conclude that a policy which would lead to adoption of something approximating a least cost strategy would save on the order of $70 million per year in the Chicago Air Quality Control Region.

EMISSION CHARGES AND/OR MARKETABLE PERMITS ARE EFFECTIVE POLICY INSTRUMENTS FOR IMPLEMENTING ATTAINMENT AND MAINTENANCE OF AMBIENT STANDARDS.

Our qualitative analysis in Chapters 3 and 4 shows that emissions charges and/or marketable permits will provide profit-and-loss incentives to firms to implement the degree of emissions control required to attain ambient standards. We also showed that the conclusion that charges and permits are effective, holds for a wide variety of assumptions about the degree of market power of sources and their organizational form. We thus have every reason to believe that charge systems and permit systems would work to implement attainment and maintenance of a short-term NO_2 ambient standard.

Most importantly, we showed in Chapters 3 and 4 that emissions charges and/or marketable permits are more efficient and effective than regulatory policies (even optimal ones) in the face of uncertainty. The practical strength of incentive-based approaches to pollution control is that they tend to divide the responsibility for decision-making along roughly the same lines that detailed knowledge about the various parameters relevant to cost-effective control is divided. The result is that economic policies may be expected to result in lower costs of pollution abatement.

> EMISSIONS CHARGES AND/OR MARKETABLE PERMITS ARE AN EFFICIENT POLICY INSTRUMENT FOR IMPLEMENTING ATTAINMENT AND MAINTENANCE OF AMBIENT STANDARDS IF THEY ARE STRUCTURED TO TAKE ACCOUNT OF DIFFERENCES BETWEEN SOURCES IN INCREMENTAL CONTRIBUTIONS TO AMBIENT CONCENTRATIONS.

Our analyses show that this conclusion is supported both on theoretical and empirical grounds. Perhaps our most surprising finding is just how inefficient a charge or permit system can be if it is not structured to take account of contribution differences. We saw in Chapters 6 and 7 that charge and permit systems which do not recognize these differences induce the adoption of control strategies that are markedly more costly than those which do. This result points to the conclusion that it is important, in structuring an incentive system, to come as close to setting incentives on a source-by-source basis, on the basis of contributions to ambient concentrations, as is possible. There are potentially enormous gains from doing so.

It does not follow, if practical considerations prohibit such fine distinctions between sources, that the case for an incentives based policy as an alternative to a regulatory one becomes any weaker. These same practical considerations will also constrain the extent to which regulations can be set in a manner to capitalize on differences between sources.

The telling advantage of a policy based on economic incentives is that it performs better under the pervasive uncertainty which surrounds the implementation of all pollution control policies. As long as the practical considerations that constrain policy are roughly similar, or pose less severe constraints on incentives as we have argued, the superior performance of economic incentives under uncertainty (see Chapters 3 and 4) tips the economic case strongly in their favor. The superior performance of incentives in inducing the development and application of emissions control technology provides still another economic argument in their favor.

> EFFICIENT EMISSIONS CHARGES AND/OR MARKETABLE PERMITS SYSTEMS IMPOSE A SMALLER ABSOLUTE BURDEN (AS MEASURED BY THE SUM OF EMISSION CONTROL COSTS PLUS CHARGE/PERMIT PAYMENTS) ON ALMOST ALL SOURCES THAN DOES ANY OTHER POLICY INSTRUMENT WE HAVE EXAMINED.

This conclusion is based on our qualitative analyses in Chapters 3 and 4, and on our analysis of Chicago data in Chapters 5, 6, and 7. By "efficient" system, we mean one which takes account of sources' contributions to ambient concentrations. Our results show that only 96 of 797 sources have to control to meet ambient standards under an efficient charges or permits program, as compared with 742 of 797 sources under an assumed likely regulatory baseline. Total control costs plus charge/permit payments are about $25 million per year under efficient charges/permits systems, as against a total annual outlay of approximately $94 million under the lowest cost assumed regulatory baseline we have examined.

In reaching the conclusion that a well-structured incentive system places a smaller economic burden on society than does regulation, we also explicitly considered the possibility that regulation could be improved to incorporate cost and effectiveness trade-offs into the regulation-making procedure. We called this brand of regulation "enlightened regulation." Our analysis in Chapters 3 and 4 showed that, due to imperfections in information, and due to differences in the amount and quality of knowledge possessed by the different "actors" involved in air pollution control decisions, "enlightened regulation" would tend to have higher costs than would a well-designed incentive system.

EFFICIENT CHARGES AND/OR MARKETABLE PERMITS REQUIRE THAT CHARGE LEVELS AND PERMIT PRICES VARY FROM SOURCE TO SOURCE. WHILE THE RESULTING CHARGE/PRICE LEVELS MAY VARY WIDELY, THEY MAY BE READILY EXPLAINABLE IN TERMS OF FACTORS RELATED TO CONTRIBUTIONS TO AMBIENT CONCENTRATIONS.

Our theoretical analysis established that efficient charge levels and permit prices generally vary from source to source. Our quantitative analysis in Chapters 6 and 7 showed that in the case of Chicago, the highest charge/price was about 700 times as large as the lowest charge/price among those sources implementing emissions controls. However, we also saw that virtually 100 percent of the variation in charge levels could be explained in terms of factors that probably correlate with incremental contributions to ambient pollution levels. While we believe that these "explanations," coupled with the fact that so many sources benefit by adoption of an efficient incentives program should be convincing, we have also demonstrated that efficient incentives can be structured so as to eliminate or reduce the variation in charge levels/permit prices. The potential savings of efficient approaches are so large, as we have concluded above, that all parties can be given incentives to find ways to implement an efficient policy.

> THERE ARE NO LEGAL BARRIERS TO THE LEGISLATION AND IMPLEMENTATION OF EITHER CHARGES OR A MARKETABLE PERMITS PROGRAM.

The analyses we have examined conclude that programs can be enacted within the legitimate constitutional powers of the government and can be implemented effectively in a manner consistent with legal constraints on the exercise of government power. However, existing legislation may need to be amended explicitly to allow the implementation of such systems.

> THE COSTS OF PUBLIC ADMINISTRATION OF EITHER A CHARGES OR MARKETABLE PERMITS PROGRAM WOULD BE EQUAL TO OR LESS THAN THOSE ASSOCIATED WITH THE USE OF AN EFFECTIVE REGULATORY APPROACH LIKE THAT CURRENTLY PRACTICED.

Our analysis shows that the incremental cost of administering, monitoring, and enforcing the control of stationary source emissions of NO_x will not be great in relation to the costs of emissions control under either regulation or an incentive-based approach. We do find, however, that these administrative costs are likely to be of approximately the same magnitude (or perhaps slightly lower) under either a charges or marketable permits program as they are under a regulatory program. The main reason for this is that effective regulation is projected to involve more investigation, negotiation, and litigation than would an equally effective incentive system.

A MARKETABLE PERMIT SYSTEM IS PREFERABLE TO A CHARGE SYSTEM FOR IMPLEMENTING ATTAINMENT AND MAINTENANCE OF THE SHORT-TERM NO_2 STANDARD.

We base this conclusion on the following findings of our analyses reported in Chapters 6 and 7:

1) To implement an efficient charge system, the charge administering agency must take the initiative to acquire information about sources' control costs. This is a difficult and expensive undertaking if costs are to be determined accurately. Under a permit system, the agency does not need to take the initiative to acquire detailed source-by-source cost data. These data are revealed as they buy and sell permits from one another.

2) A marketable permit system self-adjusts to inflation and growth. A charges system requires that the agency make adjustments to these factors, adjustments which depend upon uncertain and perhaps expensive data.

3) A marketable permit system can be made self-enforcing by providing for automatic surcharges on emissions in excess of those for which permits are held.

4) It is relatively easy to incorporate "equal treatment" considerations into the design of a permit system without affecting its efficiency.

5) A marketable permit system is administratively and legally similar to permit programs now operated under regulatory control programs. This means that it would be administered alongside of existing regulatory programs for other pollutants more easily than could a charge system. A marketable permit system is also close in spirit to the Offset Policy currently in force.

A MARKETABLE PERMIT SYSTEM IS A PRACTICAL ALTERNATIVE TO DIRECT REGULATION WHICH MAY ACHIEVE AMBIENT STANDARDS AT SIGNIFICANTLY LOWER TOTAL COST THAN WOULD DIRECT REGULATION. WE BELIEVE IT SHOULD BE GIVEN SERIOUS CONSIDERATION.

The potential gains from implementing pollution control through this type of policy instrument are great enough to warrant that the approach be given serious consideration. The design we present in Chapter 7 provides a fairly advanced starting point for a design of a marketable permit option. There are, however, a number of details that need to be worked out. How, for example, would bids and offers to sell be communicated to the market-maker? How would data be processed and disseminated to the various market participants? Will strategic behavior be a problem, and if so, how will it be dealt with? Will monopolies of permits tend to arise? How can monopolies of permits be prosecuted under laws governing restraint of trade? What is the most suitable algorithm for matching orders? Who will do the accounting? What technical assistance would be provided to the states in starting and running a marketable permits program? These are detailed practical problems that will have to be worked out before a marketable permit system can be implemented.